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REGULARITIES IN THE SPARK SPECTRUM OF HAFNIUM (HfII)[1]

By William F. Meggers and Bourdon F. Scribner

Hafnium was discovered by Coster and Hevesy[2] in January, 1923, and a list of about 800 spectral lines (2253.95A to 7240.8A) ascribed to the new element was published the same year by Hansen and Werner.[3] Without disparaging this preliminary list it was nevertheless felt that an improved description of the optical emission spectra of hafnium should precede attempts to analyse the structures of its various spectra, and the presentation of a sample of highly purified hafnium salt by Professors Bohr and Hevesy made it possible for us to study the spectra more intensively. The arc and spark spectra were photographed with our largest prism and grating spectrographs and the wave-lengths of about 1500 Hf lines were measured between the limits 2155.72A in the ultraviolet and 9250.27A in the infrared.[4] In this investigation an attempt was made to improve upon the earlier description of these spectra (1) by extending observations to shorter and to longer waves, (2) by increasing the precision of the wave-length measurements to about 0.01A, and (3) by making a more critical differentiation between lines characterising neutral atoms (HfI) and those ascribable to ionized atoms (HfII). With these new data at hand, it appeared hopeful that regularities might be found among the lines, and that conclusions as to the structures of the spectra might be drawn from such regularities.

[1] Publication approved by the Director of the Bureau of Standards of the U. S. Department of Commerce.

[2] Coster and Hevesy, Nature, 111, p. 79; 1923.

[3] Hansen and Werner, Kgl. Danske Vid. Selskab. Math.-fysiske Medd. Volume V, heft no. 8; 1923.

[4] Meggers, Sci. Pap. Bur. Stand. In press.

Our preliminary efforts to classify HfI lines have not been very successful, but the results obtained for HfII lines have exceeded our first expectations. In this paper we are describing the present status of our analysis of the HfII spectrum.

Lacking Zeeman effects, temperature classification of spectral lines, absorption data, and similar descriptive information which have aided in the analysis of other complex spectra, we have had to depend almost solely on the combination principle as a criterion for classification. Notwithstanding these handicaps, it is possible to construct a significant wave-number system for almost any complex spectrum as was indeed extensively done by Kayser,[5] by Snyder,[6] by Paulson,[7] and by others many years before the interpretation of the various descriptive data was recognized. With the development of modern ideas on spectral structures, these wave-number systems have been fully interpreted. They represent combinations between a set of low energy states of the atoms and a more extensive set of higher excited states. In most cases it has been possible with the aid of Zeeman effects, rules for level separations and for line intensities to assign quantum numbers which completely describe the spectral terms.

Even without these supplementary aids we have a considerable advantage over the pioneers in that we can now draw some inferences from comparative characteristics of the spectral lines, and instead of being puzzled by the absence of certain combinations, we have learned to rely upon the absent ones as well as upon those which do occur to assign so-called inner-quantum numbers to the energy levels. These levels comprise the components of spectral terms which are usually polyfold, but it is sometimes difficult or impossible without Zeeman effects or similar criteria to fix the absolute values of the quantum numbers which define the types and multiplicities of the spectral terms.

The procedure in constructing a wave-number system for a complex spectrum consists essentially in systematically subtracting from each other the vacuum wave-numbers of a selected group of lines and collecting the pairs of lines separated by the same wave-number difference. Each pair, if it has any physical significance, represents the combination of an atomic energy state with two other states which are common

[5] Kayser, Handbuch der Spectroscopie II, p. 573; 1902.

[6] Snyder, A wave-number system for rhodium, Astrophys. Journ., *14*, p. 179; 1901. Similar results for Pt, Pd, Ru, Os, Ir quoted by Meggers and Laporte, Phys. Rev., *28*, p. 642; 1926.

[7] Paulson, Dissertation, Lund, 1914. Astrophys. Journ., *40*, p. 298; 1914.

to all the pairs of lines having the same separation. It is perhaps not obvious, but experience has shown that in almost any complex spectrum a large number of constant differences can be found among physically unrelated lines. These are fortuitious, but sometimes mistaken for real regularities. To guard against such unfortunate accidents in the HfII spectrum, we began with a careful selection of spark lines which were observed to be developed with great intensity in the arc as well as in the spark spectrum. Assuming that such lines must involve low-energy states of the ionized atoms we soon found several levels with which many of the stronger lines could be associated. These now bear the values 3050.9, 3644.5, 6344.4 wave-number units relative to the lowest which has been found. They served as a nucleus of a significant wave-number system which by successive addition of other levels finally became the two-dimensional matrix given in Table 1. In this table the relative values for 16 levels are printed at the top, and the derived values for 27 higher states on the left margin. The level values are preceded by a number enclosed in brackets. This number represents the value of the inner-quantum number, j, which has been tentatively assigned to each level. The relative values of these inner-quantum numbers are derived from the observed combinations which appear in the body of the table, remembering that a combination is permitted only for changes of ± 1 or 0 in the value of j. The combinations are represented by the vacuum wave-numbers of the observed spectral lines. Above each wave-number is the measured wave-length and estimated spark intensity of the corresponding line. Perhaps not all of the possible combinations have been observed but on the other hand no violations of the selection rule have been observed with the assignment of j values in Table 1. The total number of lines classified in Table 1 is 206. Two of these have been used twice, two are more or less confused with zirconium and one with titanium impurities. The average deviation of the observed wave-numbers from the computed differences of the energy levels is only one-tenth of a wave-number unit, which corresp[illegible] to an average error of 0.01A in the wave-length determination[illegible] these 206 lines. This is an interesting check on the precision striven for in the wave-length measurements. The classified lines in Table 1 include a large majority of the stronger spark lines which are also present with considerable intensity in the arc spectrum, indicating that most of the very low energy levels have been identified. A more or less regular decline in average intensity of the lines associated with low levels is noticed as the energy of the meta-

TABLE 1. *Classified lines in HfII spectrum.*

		[2] 0.0	[3] 3050.9	[2] 3644.5	[3] 4904.9
			2175.32 (2)		2266.83 (8)
[3]	49005.9		45955.80		44100.80
[5]	48930.8				
[5]	47424.0				
			2266.51 (4)		2365.97 (2)
[4]	47157.7		44107.02		42253.04
			2291.65 (4)	2323.23 (6)	2393.36 (10)
[3]	46674.5		43623.20	43030.28	41769.53
			2400.81 (7)		2512.68 (30)
[4]	44690.8		41639.92		39786.17
			2417.69 (15)		2531.20 (25)
[4]	44400.0		41349.22		39495.08
		2277.15 (10)	2447.25 (20)	2483.35 (2)	2563.62 (15)
[3]	43900.6	43900.95	40849.81	40256.03	38995.66
			2460.50 (40)	2496.99 (20)	2578.15 (15)
[3]	43680.7		40629.85	40036.15	38775.90
		2322.46 (15)		2537.34 (8)	
[1]	43044.3	43044.55		39399.52	
		2351.22 (30)	2532.97 (3)	2571.68 (75)	2657.85 (6)
[2]	42518.2	42518.08	39467.49	38873.45	37613.22
[5]	42391.0				
		2393.83 (20)	2582.51 (15)	2622.75 (20)	2712.43 (10)
[3]	41761.3	41761.33	38710.44	38116.56	36856.40
			2606.38 (20)		2738.76 (25)
[4]	41407.0		38355.94		36502.09
		2467.97 (5)	2669.01 (3)		2808.00 (10)
[3]	40506.8	40506.88	37455.95		35602.07
		2591.33 (5)	2813.86 (8)	2861.69 (30)	2968.83 (25)
[3]	38578.7	38578.69	35527.93	34934.15	33673.50
			2820.23 (50)		2975.90 (30)
[4]	38498.5		35447.69		33393.50
[5]	38185.7				
		2638.72 (30)	2869.82 (4), Zr?	2919.59 (20)	3031.17 (25)
[2]	37886.0	37885.89	34835.19	34241.39	32980.99
					3126.27 (2)
[4]	36882.5				31977.76
			3000.10 (10)	3054.52 (3)	3176.86 (20)
[2]	36373.4		33322.54	32728.88	31468.55
		2861.01 (20)	3134.72 (40)	3194.20 (25)	3328.21 (5)
[3]	34942.4	34942.45	31891.56	31297.73	30037.57
		2909.91 (5)	3193.53 (15)	3255.29 (8)	3394.58 (6), Ti?
[3]	34355.1	34355.29	31304.29	30710.40	29450.30
		3012.90 (25)	3317.99 (6)	3384.70 (3)	3535.54 (20)
[3]	33181.0	33180.98	30130.09	29536.27	28276.17[a]
		3016.93 (2)		3389.83 (15)	
[1]	33136.3	33136.65		29491.57	
		3145.33 (8)	3479.28 (10)	3552.70 (15)	3719.27 (25)
[2]	31784.3	31783.99	28733.39	28139.60	26879.38
		3399.80 (40)	3793.37 (20)	3880.81 (10)	4080.44 (10)
[3]	29405.2	29405.09	26354.33	25760.54	24500.27

TABLE 1. (continued)

		[4] 6344.4	[5] 8361.8	[3] 12070.5	[2] 12920.9
		2343.32 (10)			2770.42 (5)
[3]	49005.9	42661.41			36084.98
		2347.45 (25)	2464.19 (75)		
[5]	48930.8	42586.36	40569.01		
		2433.56 (15)	2559.20 (15)		
[5]	47424.0	41079.59	39063.00		
		2449.44 (10)	2576.84 (20)	2849.21 (25)	
[4]	47157.7	40813.29	38795.61	35087.16	
				2889.01 (1)	2961.80 (8)
[3]	46674.5			34603.81	33753.42
		2607.04 (30)	2751.81 (15)	3064.68 (8)	
[4]	44690.8	38346.23	36329.00	32620.38	
		2626.97 (4)	2774.02 (10)	3092.25 (5)	
[4]	44400.0	38055.33	36038.15	32329.56	
		2661.89 (12)		3140.77 (5)	3227.00 (2)
[3]	43900.6	37556.14		31830.14	30979.62
		2677.57 (1)		3162.62 (10)	
[3]	43680.7	37336.22		31610.23	
[1]	43044.3				
				3283.40 (2)	
[2]	42518.2			30447.49	
		2773.37 (50)	2937.80 (30)		
[5]	42391.0	36046.59	34029.15		
		2822.67 (25)			
[3]	41761.3	35417.85			
		2851.21 (12)	3025.29 (8)	3407.76 (4)	
[4]	41407.0	35062.55	33045.09	29336.40	
		2926.35 (2)			3624.00 (5)
[3]	40506.8	34162.29			27585.98
		3101.38 (15)		3771.35 (4)	
[3]	38578.7	32234.39		26505.20	
		3109.11 (40)		3782.78 (5)	
[4]	38498.5	32154.25		26428.10	
		3139.67 (5)	3352.06 (20)		
[5]	38185.7	31841.29	29823.86		
				3872.54 (8)	
[2]	37886.0			25815.55	
		3273.66 (2)	3505.23 (40)	4029.16 (4)	
[4]	36882.5	30538.08	28520.67	24812.08	
				4113.58 (6)	4262.72 (3)
[2]	36373.4			24302.89	23452.62
		3495.75 (5)		4370.95 (20)	4539.74 (1)
[3]	34942.4	28598.01		22871.92	22021.34
		3569.03 (30)		4486.12 (8)	4664.13 (25)
[5]	34355.1	28010.85		22284.75	21434.24
				4735.67 (5d)	4934.44 (10)
[3]	33181.0			21110.45[b]	20260.09
					4945.36 (3)
[1]	33136.3				20215.35
				5071.21 (6)	5299.84 (6)
[2]	31784.3			19713.68	18863.26
		4335.13 (1)		5767.19 (10)	
[3]	29405.2	23060.90		17334.67	

TABLE 1. (continued)

		[3] 13485.5	[1] 15254.3	[3] 17368.9	[4] 17389.1
		2814.47 (10)			
[3]	49005.9	35520.31			
[5]	48930.8				
[5]	47424.0				
					3358.30 (4h)
[4]	47157.7				29768.45
		3012.19 (1)			3413.74 (3)
[3]	46674.5	33188.80			29285.01
		3203.68 (4)		3639.03 (3)	3661.74 (1)
[4]	44690.8	31205.12		27321.89	27301.67
		3233.80 (1)		3698.39 (7)	3701.15 (25)
[4]	44400.0	30914.48		27031.13	27010.97
[3]	43900.6				
		3310.85 (3)		3799.52 (2)	
[3]	43680.7	30195.06		26311.67	
			3597.42 (5)		
[1]	43044.3		27789.80		
			3666.77 (3d)	3975.15 (2)	
[2]	42518.2		27264.22	25149.20	
					3998.50 (4)
[5]	42391.0				25002.33
		3535.56 (20)			
[3]	41761.3	28276.17[a]			
		3580.45 (2)		4158.90 (10)	4162.04 (15)
[4]	41407.0	27921.51		24038.07	24017.85
		3699.73 (15)		4320.67 (10)	
[3]	40506.8	27021.34		23138.07	
		3984.03 (4)			
[3]	38578.7	25093.14			
		3996.80 (3)		4731.36 (9)	4735.67 (5d)
[4]	38498.5	25012.97		21129.68	21110.45[b]
					4807.14 (4)
[5]	38185.7				20796.60
			4417.35 (10)		
[2]	37886.0		22631.67		
		4272.84 (15)			5128.52 (12)
[4]	36882.5	23397.08			19493.39
		4367.89 (6)		5260.43 (15)	
[2]	36373.4	22887.94		19004.58	
		4659.20 (2)			
[3]	34942.4	21456.92			
[3]	34355.1				
		5075.91 (10)			
[3]	33181.0	19695.43			
			5590.70 (1)		
[1]	33136.3		17881.90		
		5463.36 (10)	6048.00 (3)	6935.17 (3)	
[2]	31784.3	18298.68	16529.82	14415.29	
		6279.85 (15)			
[3]	29405.2	15919.55			

a, b, used twice

TABLE 1. (continued)

		[4] 17710.7	[2] 17830.4	[4] 21637.8	[5] 23145.7
		3194.45 (2) Zr?	3206.77 (2)		
[3]	49005.9	31295.28	31175.05		
		3202.16 (2)			3877.11 (20)
[5]	48930.8	31219.93			25785.12
[5]	47424.0				
		3394.99(8)		3917.47 (6)	4163.42 (2)
[4]	47157.7	29446.74		25519.48	24011.97
[3]	46674.5				
		3705.41 (8)		4336.65 (40)	4640.13 (4)
[4]	44690.8	26979.92		23052.81	21545.11
					4703.61 (3)
[4]	44400.0				21254.34
		3817.20 (12)		4490.59 (6)	
[3]	43900.6	26189.81		22262.57	
		3849.52 (15)	3867.31 (7)	4535.36 (7)	
[3]	43680.7	25969.93	25850.47	22042.81	
			3964.95 (7)		
[1]	43044.3		25213.89		
			4049.44 (6)		
[2]	42518.2		24687.82		
		4050.68 (3)		4817.22 (12)	5194.55 (3)
[5]	42391.0	24680.27		20753.08	19245.60
		4156.74 (2)	4177.50 (15)		
[3]	41761.3	24050.56	23931.04		
				5057.03 (6)	
[4]	41407.0			19768.96	
		4385.52 (2)		5298.06 (30)	
[3]	40506.8	22795.93		18869.60	
		4790.72 (8)			
[3]	38578.7	20867.87			
		4809.18 (3)			6511.63 (4)
[4]	38498.5	20787.77			15352.90
				6041.46 (3)	6647.05 (20)
[5]	38185.7			16547.72	15040.12
			4984.75 (2)		
[2]	37886.0		20055.61		
			5247.14 (30)	6557.93 (15)	7277.68 (3)
[4]	36882.5		19052.71	15244.51	13736.87
			5391.35 (5)		
[2]	36373.4		18543.09		
		5801.71)4)	5842.23 (15)		
[3]	34942.4	17231.53	17112.02		
[3]	34355.1				
		6462.31 (4)	6512.63 (6)		
[3]	33181.0	15470.08	15350.55		
			6531.68 (5)		
[1]	33136.3		15305.78		
			7164.54 (2)		
[2]	31784.3		13953.78		
[3]	29405.2				

stable states increases and the number of apparently permitted combinations which are not observed also tends to increase with these higher levels, thus making it more difficult to recognize and establish them.

From analogy with the TiII and ZrII spectra which have been thoroughly analysed by Russell[8] and by Kiess[9] respectively it may be anticipated that the spectral terms of HfII will belong to doublet and quartet systems. According to Hund's theory, the configurations of valence electrons can produce the following low-energy spectral terms in these spectra:

Electron configuration: d^2s. Spectral terms: ^2S, $^2P'$, ^2D, $^2F'$, ^2G, $^4P'$, $^4F'$. Electron configuration: d^3. Spectral terms: $^2P'$, ^2D, $^2F'$, ^2G, $^2H'$, $^4P'$, $^4F'$.

The total number of levels forming these terms is 33, about twice as many as we have found in HfII. This indicates that our analysis is still far from complete and warns us against attempting to draw conclusions as to the relative positions of analogous terms in the different spectra. It may, however, be pointed out that although in TiII and in ZrII the normal state (zero energy) is represented by $^4F'$ (d^2s), another term, ^2D, originating with the same electron configuration, d^2s, has dropped from 8710 in TiII to 4248 in ZrII. If this tendency continues, in approaching HfII, we may be justified in regarding the levels [2] 0.0 and [3] 3050.9 as $^2D_{2,3}$, and the next four levels, viz. [2] 3644.5, [3] 4904.9, [4] 6344.6, [5] 8361.8, as $^4F'_{2,3,4,5}$. This point and the complete specification of the remaining levels in both sets will be cleared up when our analysis of the HfII spectrum is more complete, and supplemented by observations of Zeeman effects.

BUREAU OF STANDARDS,
WASHINGTON, D. C.
MAY 8, 1928.

[8] Russell, Astrophys. Journ., *66*, p. 283; 1927.
[9] Kiess and Kiess, Sci. Pap. Bur. Stand. In press.

THE TIME INTERVALS BETWEEN THE APPEARANCE OF SPECTRAL LINES IN THE SPECTRA OF ALKALI AND ALKALINE-EARTH METALS

By Gordon L. Locher

ABSTRACT

Using the method of Beams and others, the time intervals between the appearance in spark discharge spectra of about fifty lines of sodium, lithium, calcium, barium, strontium, magnesium, cadmium, zinc, and nitrogen were measured for the purpose of determining if there was any relation between these times and the nature of the lines or the positions of the elements emitting them in the periodic table. The time intervals for different lines varried from zero to about 2×10^{-8} second. Most of the lines seemed to be emitted at the very beginning of the discharge, before the potential across the spark gap had dropped appreciably, There did not appear to be any definite relation between the time intervals and the nature or origin of the lines. With one exception, the members of multiplets which could be resolved appeared simultaneously.

A variation of the time intervals with the amount of inductance in the spark gap circuit was observed and an explanation of this is given; the times were independent of the other electrical characteristics of the circuits. In a qualitative theory of the beginning of spark discharge spectra, it is suggested that the time of appearance of any line depends not only on the "life" of the excited atoms, during which there is no emission, but also on the minimum current in the discharge required to excite the line with a visible intensity.

Using the method of Abraham and Lemoine in a considerably modified form, Beams,[1] and others,[2] have measured the time intervals between appearance of spectral lines in the spectra of spark discharges for about seven elements, finding these to be of the order of 10^{-7} to 10^{-8} second. Their work indicated that spark lines appeared before arc lines, consistently, for the elements examined.

It was proposed to extend this work to other elements, with the particular purpose of determining whether or not there was any simple relation between the grouping of the elements in the periodic table and the time intervals between the appearance of corresponding lines in their spectra. Groups 1 and 2 were examined.

EXPERIMENTAL ARRANGEMENTS

The arrangement of the apparatus, shown in Fig. 1, is essentially the same as that used in the researches described above, the chief modification being the substitution of a fixed light path for the variable one.

The high-tension transformer, T, charges up the spark-gap which gives a succession of sparks; the brilliancy of these is augmented by the condenser, C, which is of small dimensions and is closely attached to the electrodes of the gap. In order to prevent objectionable

[1] Beams, Phys. Rev., *28*, p. 475; 1926.

[2] Beams and Rhodes, Phys. Rev., *28*, p. 1147; 1926; also Brown and Beams, J. O. S. A. and R. S. I., *11*, p. 11; 1925.

oscillations in the transformer secondary, the water resistances, R_2, are provided. A pair of variable inductances consisting of four long, symmetrical, parallel wires, W, connect the spark gap to the Kerr cell, S; the effective lengths of these wires are altered by sliding the trolley, t, along them by means of a thread running over a system of pulleys to the observer's position.

Considering the optical system, light from the gap is reflected by a large concave parabolic mirror, M, through the right angle prism, P, and Nicol prism, N_1, being focused between the plates of the Kerr-cell, S. A small convex lens focuses the beam again at the slit of a Hilger wavelength spectrometer, after passing it through another Nicol prism, N_2. By slightly turning P, any portion of the horizontal image of the gap can be examined.

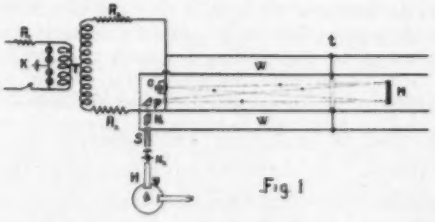

Fig. 1

The electro-optical shutter consists of a Kerr-cell, S, with its plates vertical, and the nicols N_1 and N_2, these latter being crossed and each with its plane of polarization set at 45° to the vertical. Ordinarily, the optical path is not open, but when a sufficient potential is applied to the Kerr-cell, the liquid in it becomes doubly refracting and light can pass through the shutter. Since the electro-optical rotation is proportional to the square of the field in the dielectric of the cell, opening and closing of the shutter is very sharp when the critical potential is passed; this fact is of the utmost importance in connection with the use of the shutter for this kind of work. The Kerr-cell consists of a pair of brass plates 15 cm long and 4 mm apart, supported in chemically pure carbon disulphide by bakelite posts (bakelite being insoluble in that liquid). The capacity is estimated at 20 cm; fields of about 32,500 volts/cm were found most satisfactory although the cell operates with fields as small as 12,500 volts/cm and did not break down up to 45,000 volts/cm.

To show how the apparatus operates, suppose the spark gap to be charging up to the sparking potential which is a little greater than the opening potential of the shutter. When the spark occurs, a beam

of light starts down the optical path to the spectrometer; simultaneouly, a collapse of potential difference begins at the gap and proceeds along the wires, W, to the shutter at approximately the speed of light.[3] When the pulse reaches the shutter, it closes almost instantly. If the emission of light by the gap were simultaneous with the collapse of potential across it, and if the length of each of the wires, W, were made equal to the length of the light path, the light would arrive at the shutter just when the shutter was closing, hence a slight displacement of the slider, t, toward the gap would cut out the light while a similar displacement in the other direction would make the pulse visible to the observer.

Actually, the emission of the several spectral lines is not simultaneous, so these lines can be made to appear a few at a time by sliding the trolley along. The time differences between the appearance of two lines is, approximately, the difference between the lengths of the inductance wires, as set for their appearance, divided by the speed of light.

When examining spectra obtained from a discharge between knife-edged electrodes of the metallic element under examination, the position of the image of the spark on the slit of the spectrometer is important. Since the metallic vapor does not migrate far from the electrodes, only the edges of the spark image contain the required light. The position of the slit was adjusted with the nicols crossed and with the leads, W, as short as possible, so as to obtain as great an intensity of the light as possible.

For elements which are not available in the metallic state, or which are difficult to handle in that state, spectra were got from solutions of their salts. For this purpose, a vertical gap was made; the upper electrode was a carbon arc pencil while the lower was a shallow glass cup containing the solution of the salt. Because of splashing and evaporation, the water required constant replacement; this was effected by a slow drip from a funnel. Obvious difficulties with the insulation made it necessary to put the condenser, C, at a considerable distance from the gap. With salts of the alkali metals and some others, an arc, rather than a spark was formed if a single gap was used. To prevent this and to secure a sufficient drop of potential over the shutter, a series gap, placed very near to the other, was introduced.

Once the apparatus is adjusted, observations can be taken with considerable rapidity. The trolley, t, is run back so that the effective length of the wires, W, is as large as possible and the spectral line under examination is at a maximum intensity. The trolley is then advanced,

[3] F. Allison, Phys. Rev., *30*, p. 66; 1927.

shortening W, until the line is no longer visible; this position of t is recorded. Reversing the direction of the trolley, the position of first appearance is then found; this does not, in general, differ appreciably from the previous position. The actual "position for appearance" of any line is taken as the mean of these two values. The relative times of appearance of the lines are then easily calculated.

EXPERIMENTAL RESULTS

"Limits of Error" are estimated with each observation and are recorded in terms of the equivalent time. Thus $.2\times10^{-8}$ second means that the line may appear $.1\times10^{-8}$ second earlier or later than the time recorded.

The "Intensity" values are taken from Kayser's "Handbuch der Spectroscopie," Band 9, being the intensities for "spark" lines.

A fictitious spectral line for which the trolley-wire length for appearance is just equal in length to the light path, may conveniently be taken as appearing at zero time; real lines appearing earlier than this (i.e. for W shorter) have, then, negative times of appearance, while those appearing later have positive times of appearance. If the Kerr shutter closes instantly, within the limits of error, when the fall of potential has traveled down the wires to it, then the fictitious line would be emitted in the spark at the same instant that the potential difference across the gap fell below the opening potential of the shutter. For tabulation of the data below, the time of appearance of the fictitious line is recorded as T_0 and the appearance of other lines is reckoned positive or negative from this. Thus:

$$T_0=\frac{\text{Length of light path}}{c}$$

The lines for each element are listed in the order of their appearance.

TABLE 1. *The alkali metals.*

	Element	Wave length	Limit of error $\times10^8$ sec	Intensity	Time of appearance from $T_0\times10^8$ sec
1.	Na*	5890 5896	.07	20	−1.74
2.	Li	6103	.13	10	−2.3
3.	Li	6708	.40	20	+1.5

* The appearance of this doublet was very sharp.

Only a few of the more intense lines of the spectra of these elements lie in the visible, and of these only three were obtained with sufficient intensity to examine by the methods of these experiments.

The light path was 800 cm, and the length of each lead from the spark gap to the spark condenser was 55 cm.

TABLE 2. *The alkaline-earth metals.*

Spectra of calcium, barium, and strontium were obtained by sparking to chlorides of these metals; the spectrum of magnesium was excited by a discharge between electrodes of the metal.

For calcium, barium and strontium, the light path was 800 cm and the length of each lead from the spark gap to the condenser was 55 cm. The corresponding lengths for magnesium were 540 cm and 10 cm, respectively.

	Element	Wave length	Limit of error $\times 10^8$ sec	Intensity	Time of appearance from $T_0 \times 10^8$ sec
		6170		4	
		6161		4	
4.	Ca*	6156	.20	—	−1.2
		6169		4	
		6164		4	
		6166		4	
5.	Ca	6500	.13	4	− .63
		5601			
6.	Ca	5595	1.30	8	+1.1
		5590			
7.	Ba	5535	.07	10	−1.92
8.	Ba†	4934	.07	10	−1.85
		4554			
9.	Ba	6141	.13	20	−1.37
10.	Ba	5853	.10	10	− .11
11.	Ba	6497	.20	10	0.0
12.	Sr	5521	.07	7	−1.84
13.	Sr	4215	.13	30	−1.74
		5535		7	
14.	Sr	5504	.13	8	−1.71
		5484		4	
15.	Sr	5257	.13	6	− .69
16.	Sr	4607	.07	20	− .34
17.	Sr	4305	.13	20	− .26
		5184		20	
18.	Mg	5173	.07	15	−1.31
		5167		10	
19.	Mg	4703	.20	5	− .99
20.	Mg	4481	.13	20	− .99
21.	Mg	5528	.13	4	− .89

* A "band" with wide spectrometer slit.

† These lines were observed separately; the agreement is excellent.

TABLE 3. *Nitrogen, zinc and cadmium.*

A few strong nitrogen lines, obtanied by a discharge between cadmium electrodes in air, were examined. The spectra of zinc and cadmium were obtained from discharges between electrodes of the metals.

Except for observation 29, the length of each lead from the spark gap to the condenser was 10 cm; the light path was 532 cm for some observations and 545 cm for others.

	Element	Wave length	Limit of error $\times 10^8$ sec.	Intensity	Time of appearance from $T_0 \times 10^8$ sec.
		5001			
22.	N_2*	5003			$\ll -1.5$
		5005			
		5008			
		5679			
23.	N_2*	5676			< -1.5
		5667			
24.	N_2	5942	.07		−1.27
		5932			
25.	N_2	5045	.07		−1.20
26.	Zn	4912	.13	20	−1.00
		4924			
27.	Zn§	4811	.17	20	−1.05
28.	Zn	4722	.33	20	− .53
(29)	Zn‡	4912	.17	20	+ .85
		4924			
30.	Cd	5337	.07−	10	−1.27
		5378			
31.	Cd	5086	.07	8	−1.13
32.	Cd†	4800	.07	10	−1.11

* Still visible with the trolley at a minimum.

§ 4811, 4722 are members of a triplet. These do not appear simultaneously here.

‡ With 115 cm of wire for each lead from condenser to spark gap.

† Appears with 5086 within limits of error.

Observations 26 and 29, Table 3, indicate the effect of changing the length of the wires connecting the condenser, *C*, to the spark gap. In order to investigate this more fully, a series of observations was made on the prominent lines of the cadmium spectrum, with leads of various lengths. No effect was observed due to changing the capacity of the condenser, but that due changing the length of the leads to it was conspicuous. The sharpness of appearance of the lines was not altered by changing these lengths; nor did the substitution of fine wire of about 50 ohms resistance for the heavy copper leads affect the sharpness or time of appearance of the lines. Table 4 and Fig. 2 show the effect

on the appearance of the cadmium lines due to altering the lengths of the leads. An interpretation of this effect is presented later.

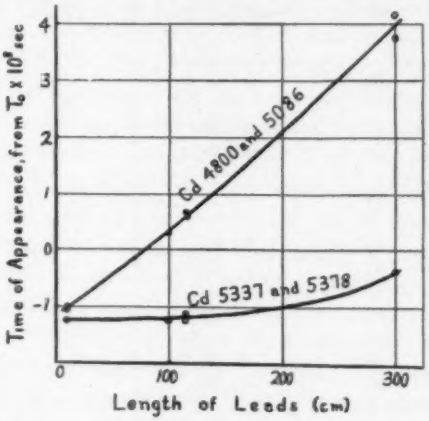

FIG. 2. *Showing how the time of appearance of two cadmium doublets varied with the inductance in the spark gap circuit.*

DISCUSSION OF RESULTS

Sharpness of appearance of lines. Not all spectral lines appear with the same degree of sharpness. There is, however, apparently no general rule about the relation of the sharpness of appearance to the nature of the line with respect to wavelength, series, breadth, or intensity. The accuracy of setting of the trolley is not constant but is estimated with each observation and tabulated with the other data. An obvious disturbing element for any observation is the presence of an air line superposed on, or in close proximity to, the line being examined. Lines of the extreme red (longer than 6500) and of the violet (shorter than 4500) are more likely to be in error than those between these limits, because of the diminishing sensitivity of the eye for light near the extremities of the visible spectrum; most of the lines observed lie in the range of good visibility.

Order of appearance of members of multiplets. Wherever it was possible to resolve them, the appearance of members of multiplets was carefully examined. The lines of the widely separated doublet 4934, 4554, due to singly ionized barium, appear together to a high degree of accuracy; likewise those of the cadmium doublets 5337, 5378 and 4800, 5086 and the *D*-lines of sodium. In the case of the zinc lines 4811 and

TABLE 4. *Cadmium.* Light path: 800 centimeters.

	Wave length	Limit of error $\times 10^{9}$ sec.	Time of appearance from $T_0 \times 10^{9}$ sec.	Relative times $\times 10^{9}$ sec.	Length of wire in each lead from condenser to gap in cm
	5337	.03	−1.24		
	5378			1.53	
A	5086	.07	+ .29		100
	4800	.07	+ .29		
	5337	.07	−1.11		
	5378			1.74	
B	5086	.10	+ .66		115
	4800	.07	+ .61		
	5337	.03	−1.25		
	5378			.18	
C	5086	.07	−1.07		10
	4800	.07	−1.07		
	5337	.03	−1.23		
	5378			.23	
D	5086	.07	−1.00		10
	4800	.07	−1.00		
	5337	.03	−1.24		
	5378			1.84	
E	5086	.07	+ .60		115
	4800	.07	+ .56		
	5337	.16	− .36		
	5378			4.55	
F	5086	.10	+4.19		300
	4800	.20	+3.78	.41	

4722, which are members of a triplet, there was an interval of about $.5 \times 10^{-8}$ second between the appearance of the lines; this was the only case observed where the members of a multiplet did not appear together within the limits of error.

Lines appearing earlier than T_0. The times of appearance of most of the lines examined in this work are *negative* with respect to T_0, which means that they appear before the main collapse of potential begins at the gap, unless the shutter requires a relatively long time to close. There is, undoubtedly, a small constant lag in the opening and closing of the shutter, namely the time required for the double refraction to become established or vanish in the dielectric of the cell. Many of the lines observed appear as much as 10^{-8} second earlier than T_0;

but this is a thousand times as long as is required to establish a field in the dielectric of the cell, hence it seems improbable that the lag of its operation would be as great as 10^{-8} second. Observations were made with various potentials on the shutter, including the minimum value for its operation, to determine whether or not the lag depends on the potential. The results were the same for any voltage, which shows that the lag in the cell is constant throughout the range of voltage used.

Oscillations in the electric circuits. High frequency oscillations in the circuit containing the Kerr cell were examined with a wavemeter. Such oscillations, if of suitable frequency, might open and close the shutter several times during each spark or might set up standing waves in the trolley wires which would interfere with the normal operation of the shutter. For sets *C* and *D* of Table 4, there were oscillations with a frequency of 6×10^6 cycles/sec when the trolley wires were as short as possible; this was the highest frequency that was detected with any arrangement of the apparatus. For set *F*, it was about half as great, and in no case was the amplitude of the oscillations large. An increase in the effective length of the trolley wires further diminished the frequency and amplitude of the waves. The period of these oscillations is of the order of a hundred times as great as the times measured in these experiments and the least wavelength emitted is about ten times as long as the average length of the trolley wires, which excludes the possibility of standing waves in the wires. Hence it is concluded that any oscillations present do not interfere with the experiment.

Wave length and order of appearance of lines. Consider two lines of equal intensity, *A* and *B*, of which *A* has the longer wavelength. If the energy required for the excitation of atoms is proportional to the frequency of the light emitted by them, one would expect *A* to appear before *B*. But if the lines are listed in the order of their actual appearance, the order of their wavelengths is random. Therefore the lines are either not excited in the order of their wavelengths or the excited atoms do not begin to emit immediately after excitation. The excitation of lines is discussed in the next section.

Experiments of Wood,[4] Gottling,[5] and Hoxton and Beams[6] have shown that there is a measurable lag before the beginning of fluorescent emission after light has been allowed to fall on a fluorescent substance.

[4] Wood, Royal Soc. Proc., A *99*, p. 362; 1921.
[5] Gottling, Phys. Rev., *22*, p. 566; 1923.
[6] Hoxton and Beams, Phys. Soc. Bull., Dec. 12, 1925.

It seems reasonable to suppose that there may be a similar phenomenon connected with the beginning of spectra of discharges: that is, a minimum time after excitation which must elapse before the beginning of emission. If this is different for different spectral lines, the lack of correspondence between the order of appearance and order of wavelengths can be qualitatively accounted for.

Excitation and appearance of lines in a spark discharge. If the intensity of a source of light is steadily increased from zero, it "appears" or "becomes visible" to an observer when it reaches a certain fairly definite intensity. In the case of light from a spark gap, this minimum intensity for visual detection must be a function of the current in the discharge, probably being proportional to it. This suggests that the current in the discharge may be the most important factor to consider in the study of the beginning of spark spectra.

The effect of inductance in the circuit containing the gap and condenser is to delay the arrival at the gap of the energy stored in the condenser, when the discharge begins. The result is a displacement and alteration of the current curve, as from I_1 to I_2, Fig. 3. An ex-

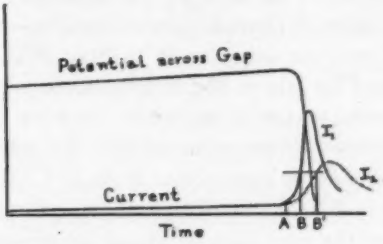

FIG. 3

planation of the results of Table 4 can be had if we suppose that a certain intensity of current is required for the excitation of any particular line to a sufficient intensity to render it visible to an observer. Then the time of appearance of lines requiring only a small current for their excitation, such as A, may not be affected by a small displacement of the current peak, while those like B, requiring a large current, will be made to appear later (B'). But for a large displacement of the current curve, corresponding to the introduction of considerable inductance, there may be a change in the time of appearance of lines of the first type. The data in Table 4 are in accord with this idea; the doublet 5337, 5378 is of the first type, while 5086, 4800 is of the sec-

ond. The greater effect of the change of length of the condenser leads on the latter than the former is shown by Figure 2. The two nitrogen groups recorded in observations 22 and 23 seem to be other examples of the low-excitation-current type of lines.

It seems, then, that there must be at least two, and possibly more factors determining the time intervals between the appearance of spectral lines, namely, the current required to excite the line to a visible intensity and the life of the atoms in the excited state. This being the case, it is difficult to make an estimate of the relative importance of these factors in determining the time of appearance of any line, by experiments such as those described here.

In conclusion, the writer wishes to express his sincere thanks to Professor H. A. Wilson, under whose direction this work was done, for his valuable suggestions and criticisms of the performance and interpretation of the experiments.

THE RICE INSTITUTE,
HOUSTON, TEXAS,
FEBRUARY 19, 1928.

SPARK SPECTRA OF MERCURY VAPOR

By Joseph Valasek

In 1923, L. and E. Bloch[1] published a list of 300 spark lines of mercury vapor which were obtained by observing an electrodeless discharge. It was found that as the length of the spark gap in the primary of the Tesla coil was increased, the spark lines could be separated into three groups which were designated as the E_1, E_2 and E_3 spectra in the order of their appearance. Using the electron impact method, Dejardin[2] found some of the radiation potentials. He divided Bloch's E_1 group into two groups which he designated by E_1 and E_1'. He found that the E_1 lines appeared at 20 volts, the E_1' lines at 30 volts, and the E_2 lines at 44 volts. Recently this work was repeated by Eldridge,[3] who found, instead of the above values, 18 volts for E_1, 24 volts for E_1' and 57 volts for E_2. Dejardin suggests that the E_1 lines are the first spark lines of mercury. This is supported by Smyth's[4] work on positive ray analysis in which it is shown that Hg^{++} begins to appear at about 20 volts. A further confirmation is found in Carroll's[5] investigation of some spark spectra by means of a vacuum spectrograph, and the partial classification of the first spark spectrum. Dejardin also suggests that the E_2 lines belong to the second spark spectrum, that is, the complete group appears simultaneously with the formation of Hg^{+++}, and that the E_3 lines are accompanied by the formation of Hg^{++++}. This has, however, not been verified.

The present investigation deals with the location of the E_3 radiation potentials. These potentials probably give the energy required to produce excited and ionized Hg^{+++}. It is also shown that the atoms are usually excited by a single impact. This is shown by measurements of intensity. If the atom emitting certain spectrum lines is excited by a single impact, the intensity of the lines should increase in the same proportion as the electron current. If two collisions are required, to bring the atoms into the initial excited state, the number of excited atoms, and therefore the intensity of the lines, should increase as the

[1] Bloch and Bloch; J. de Phys., *4*, pp. 333–348; 1923.
[2] Dejardin; Ann. de Phys., *2*, pp. 241–327, 1924; C. R. *183*, p. 1340, 1926.
[3] Eldridge; Phys. Rev., *29*, p. 213; 1927.
[4] Smyth; Proc. Roy. Soc. A. *102* pp. 238–293; 1923.
[5] Carroll; Phil. Trans. A., *225*, pp. 357–420; 1926.

square of the current, etc. If only one electron can be removed from an atom at one impact, the E_3 lines, if due to the formation of Hg^{++++} should vary in intensity as the fourth power of the current. Of course, one may have some atoms excited by a single impact and others by multiple impacts, in which case the intensity variations will not be exactly integral powers of the current ratios. It should, however, be possible to find the predominant mode of excitation under the conditions of the experiment.

The apparatus was practically the same as described in a previous article.[6] The tube was kept at a few degrees above room temperature to obtain a greater intensity. Care was taken not to decrease the mean free path of the electrons so that they would collide more than

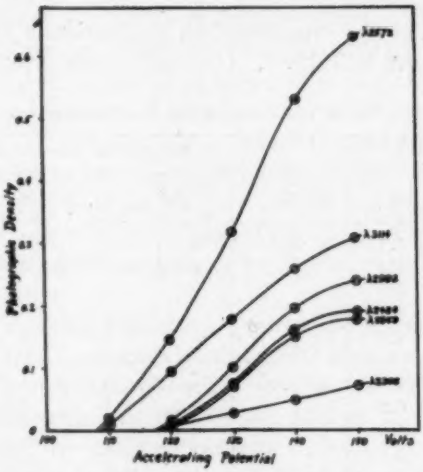

FIG. 1. *Radiation potentials of the E_3 lines.*

once, and thus increase the intensity of the arc spectrum at the expense of the spark lines.

To obtain the potentials at which the E_3 lines made their appearance, the accelerating voltage was increased by steps (usually of 10 volts) and a set of photographs taken with the plate current constant. The photographic densities of some of the E_3 lines were measured by means of a Moll microphotometer. These were plotted against the voltage with the results shown in Fig. 1. At least two critical potentials are found,

[6] Valasek; Phys. Rev., *29*, pp. 817–821; 1927.

namely, 108 and 118 volts. Besides the lines shown in the figure, the following were also observed; 3968, 3355, 3331, 2810, 2432, 2272. The intensities of these lines were too low to measure with sufficient accuracy. The values of the critical potentials obtained in the above manner were found to be dependent, to a certain extent, on the current density. That used in the above case was approximately 0.4 milliamperes per square centimeter. With a current six times as large, the critical potentials seemed to be ten volts lower, but the curves did not approach the axis as steeply, indicating secondary cumulative effects. For this reason it is though that 108 and 118 are about the correct values for the excitation of the lines by a single impact. In a similar manner the values 47 and 55 volts were obtained for some of the E_2 lines.

The results of the experiment on the variation of intensity with current are shown in Table 1. The first column gives the accelerating

TABLE 1. *Intensity ratios for tripled current.*

Acc. pot. volts	Class of lines				
	Arc	E_1	E_1'	E_2	E_3
160	*a* 3.1 *b* 4.2 *c* 3.7 *d* 4.4 *e* 4.7	*k* 3.6	*m* 1.9 *n* 3.3	*p* 2.1 *q* 1.8	*r* 3.0 *s* 3.5
60	*a* 3.5 *b* 4.6 *c* 3.5 *f* 3.6	*k* 3.0	*m* 2.1	*p* 3.3 *q* 3.3	
35	*c* 2.6 *h* 2.9 *i* 3.5 *j* 3.3	*k* 2.8	*n* 2.9		
23	*c* 3.7 *i* 3.6	*k* 3.1 *l* 2.9			

voltage, the other columns give the intensity ratios for the five classes of lines when the electron current is increased by a factor of three. The letters serve to identify the lines, the wave lengths of which are given in Table 2. The potentials where chosen somewhat above the minimum values needed to excite the various groups of spark lines. It is seen

TABLE 2. *Wave lengths of lines in Table 1.*

Line	Wave length	Line	Wave length
a	4916 A. U.	*k*	2848 A. U.
b	2967	*l*	3893
c	2857		
d	2576	*m*	3208
e	2561	*n*	2947
f	3342		
g	2675	*p*	4797
h	2925	*q*	3312
i	2760		
j	2753	*r*	3114
		s	2572

that in no case is the increase in intensity much different from linear. In fact, the arc lines increase more than the spark lines of any group. It is certain that the intensities of none of the spark lines increase by factors of 9, 27, or 81, as would be expected if two, three, or four impacts respectively were necessary to produce the initial excited atom. It is certain that the E_1 lines are the first spark lines, and it is probable that the E_2 and E_3 lines are higher order spark lines. Hence, one may conclude that when atoms are multiply ionized, it is usually by a single impact. The prominence of the spark lines in the spectrum indicates that no small fraction of the impacts by high velocity electrons result in multiple ionization.

A search was made for critical spark potentials higher than 118 volts. Accelerating potentials as high as 1200 volts were used. It was once thought that the existence of such potentials was shown by the appearance of prominent lines at 3078 and 3303 A. U. but it was later shown that these lines really appear with E_1 lines if a sufficiently long exposure is given. It is rather peculiar, however, that they should be much enhanced by the use of potentials close to 1000 volts. They differ in this respect from other lines in their neighborhood.

The writer believes that the E_1 group should not have been divided into only two groups, appearing respectively at 20 and 30 volts, according to Dejardin, and 18 and 24 volts, according to Eldridge. What seems much more probable is a step by step excitation of the spectrum. This is also true of the E_2 and E_3 spectra. In the case of spark spectra there are so many ways of exciting the lines that it is not as easy to obtain clear cut results as in the case of the arc spectrum. Assuming excitation by single impact and using Carroll's values for the energy levels in the singly ionized mercury atom, one obtains the following

TABLE 3.

Wave length	Notation	Rad. Pot.	Wave length	Notation	Rad. Pot.
1942	$1S-2p_2$	16.8	2253	$2p_1-3d_1$	23.4
1650	$1S-2p_1$	17.9	1869	$2p_2-3d_2$	23.4
2260	$2p_2-2S$	22.2	4825	$3d_1-4f$	25.9
2848	$2p_1-2S$	22.2	4960	$3d_2-4f$	25.9
2225	$2p_1-3d_1$	23.3	Double ionization		29.4

minimum potentials for the appearance of some of the first spark lines. It is seen that these potentials are not very different from the values observed by Dejardin and Eldridge in the case of the E_1 and E_1' groups. Thus it appears likely that they both refer to the first spark spectrum. The classification of the lines is as yet too incomplete to determine whether the two groups belong to the same spectrum.

DEPARTMENT OF PHYSICS,
UNIVERSITY OF MINNESOTA,
MARCH 1, 1928.

Experimental Radio—R. R. Ramsey, Professor of Physics, Indiana University, XII, 229 pages including 152 figures. Ramsey Publishing Company, Bloomington, Indiana. $2.75.

This is the third edition of a laboratory manual first published in 1923. It describes 117 experiments used by the author's students in a second year physics course. Notes are given on the construction of special radio apparatus. Among the more important topics covered we may mention; construction and measurements of the capacity, resistance and phase angle of a radio condenser; methods of measuring inductances; the calibration and use of the wavemeter; determination of the natural wave-length, capacity and inductance of an aerial; vacuum tube characteristics; a study of the vacuum tube as an oscillator; construction and measurement of the amplification of audio-amplifiers; construction and adjustment of neutrodyne, reflex and superheterodyne receivers; methods of measuring radio frequency resistance of wires, coils, oscillating circuits, aerials, and condensers; decrement of a sending station and use of the decremeter; construction and adjustment of a radio phone transmitter; methods of modulation; use of crystal control for a constant frequency circuit; measurement of power in radio circuit and field intensity determinations.

The experiments are simple and theory is given only for some of the more advanced experiments. Elsewhere references are given to well known books and periodicals. The radio experimenter and amateur should find this book an excellent guide. It is a practical manual for the laboratory not abundantly equipped with specialized radio apparatus.

GRACE HAZEN RUARK

THE DEPENDENCE OF THE RESOLVING POWER OF A PHOTOGRAPHIC MATERIAL ON THE WAVE LENGTH OF LIGHT*

By Otto Sandvik and George Silberstein

In two earlier papers one of the authors has shown the dependence of the resolving power of a photographic material upon the type or geometrical shape of the object,[1] and second, upon the contrast in the object.[2] The present paper gives the results of a preliminary experimental investigation of the dependence of the resolving power on the wave length or on the spectral quality of two adjacent images

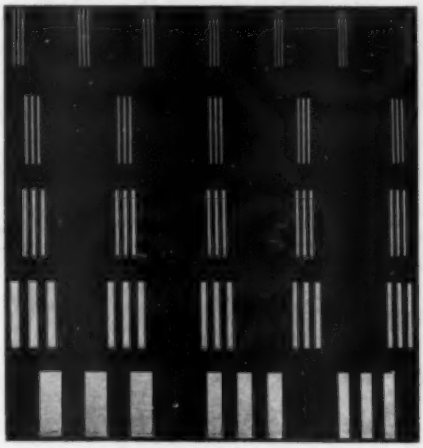

Fig. 1. *Parallel line test object.*

to be resolved. The spectral region which has been investigated extends from wave length 380 mμ to wave length 725 mμ.

The method employed in the present investigation was similar to the method previously employed, namely, to photograph in a re-

* Communication No. 344 from the Kodak Research Laboratories.

[1] Otto Sandvik. On the Measurement of Resolving Power of Photographic Materials. J.O.S.A. & R.S.I., *14*, p. 170; 1927.

[2] Otto Sandvik. The Dependence of the Resolving Power of a Photographic Material upon the Contrast in the Object. J.O.S.A. & R.S.I., *16*, p. 244; 1928.

ducing camera a parallel-line test object shown in Fig. 1. This consists of twenty-five groups of parallel lines; each group contains three transparent lines on an opaque background and separated by two opaque spaces; the width of the lines equals the width of the spaces in each group. The distance between the centers of two consecutive lines or spaces will be designated by d. The distance d varies among the groups from 0.13 to 2 mm.

The reduction in the camera is 20 diameters, hence the resolving power, R, in terms of number of lines per millimeter which are resolved, is given by the relation,

$$R = 1/0.05d$$

Thus the range of resolving power values covered by the groups of lines on the test object when photographed in this camera at a reduction of 20 diameters will be from 10 to 154.

As already pointed out, the resolution obtained depends on the contrast in the object; therefore the conrrast in the object selected was sufficiently high to obtain practically the maximum resolution.

The arrangement of the apparatus is shown in Fig. 2. C_1 is a condenser lens imaging the light source, S, on the entrance slit of the

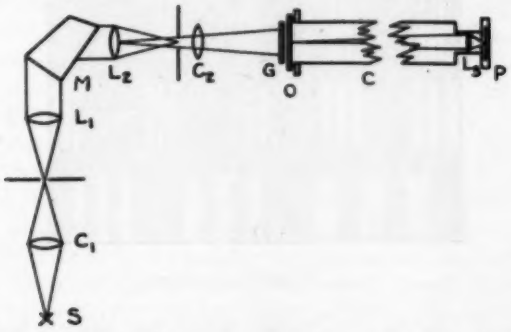

FIG. 2. *Schematic diagram showing the arrangement of the apparatus.*

monochromatic illuminator, M; C_2 is a cylindrical lens which is so placed as to image the collimator lens, L_2, on a ground glass which is in contact with the test object O. This arrangement gives uniform illumination of quite homogeneous spectral quality over the entire test object. The object, O, was then imaged on the photographic plate, P, by L_3, which is a well corrected single achromatic lens of six-inch focus.

Four series of exposures were made through the test object for each wave length and developed to four different gammas. The consecutive exposure times were increased by powers of two from 1/4 second to 1024 seconds. Then by microscopic examination of the series of images resulting from these developed series of exposures, the maximum resolving power was determined for the several different values of D, the density of the images.

The relation between resolving power and wave length for several emulsions is shown in Table 1 and Figs. 3 and 6 to 10 inclusive. The

TABLE 1. *Mean value of resolving power*

TABLE 1. *The table below shows the change in resolving power with wave length for several emulsions. Column 1 gives the wave lengths in mμ and columns 2 to 7, inclusive, give the resolving powers at these wave lengths of the respective emulsions designated at the top of each column.*

λ	W & W Panchromatic	Eastman D.C. Ortho	Eastman Speedway	Eastman 40	Eastman 33	Eastman Process
380	90	86	90	79	100	119
400	92	86	85	79	100	109
425	81	74	73	74	96	104
450	73	68	63	66	86	94
475	55	49	48	51	63	76
500	56	50	46	44	56	
525	63	56	42	44	55	
550	64	60	40	43	57	
575	65	61		45		
600	63	55				
625	59					
650	61					
675	59					
700	59					
725	59					

first column of the table gives the wave lengths in mμ and columns 2 to 7 inclusive give the mean values of the resolving powers for the four development times.

Referring now to Fig. 3, which represents graphically the relation between resolving power and wave length for the Eastman 40 plate, it is seen that the maximum value of resolving power in the spectral region investigated occurs in the near ultraviolet or the violet, with a rapid decrease in the blue-green reaching a minimum value at about wave length 535. It is of interest to note that the spectral region of decreasing resolving power conforms fairly well with the region of decreasing opacity or absorption of the emulsion, Fig. 4. This, of

course, is what one would expect, since where the opacity is high, that is, where there is a high extinction coeffiient, the photographic image is confined more to the surface than where the opacity is low; and it

FIG. 3. *Graph showing the relation between wave length and resolving power for the Eastman 40 plate.*

is a well known fact that a surface image gives much higher resolution than one which penetrates far into the emulsion. This is true whether the surface image is attained by little exposure, by under-develop-

FIG. 4. *Curve showing the change of absorption of the Eastman 33 emulsion with the wave length.*

ment, by the screening action of a dyed emulsion, by physical development, or by a thin coating of emulsion.

That the observed change in the resolving power with wave length cannot be accounted for wholly on the basis of a change in the opacity

of the emulsion is apparent when one compares the increase in the resolving power with a continuously decreasing opacity on the long wave length side of λ535. This may be accounted for probably on the basis of a practically constant absorption coefficient together with a change in scattering characteristics and increase in gamma of the emulsion with wave length.

It may be of interest to compare the change in resolving power with wave length to the change in the density edge gradient or the sharpness with wave length in the spectral region neighboring λ535.

Before doing so, however, it may be well to consider briefly the density gradient at the edge of a photographic image. This gradient is evaluated in the following manner: A carefully made edge is placed in contact with the emulsion surface when exposures are made with collimated light so that the direction of the ray is normal to the emulsion surface. This method of obtaining a sharp image edge eliminated imperfections in the image due to flare, aberrations, and other defects in the optical systems. Hence a photographic image is obtained whose finite density gradient at the edge is due partly to spreading of the silver image on development, but chiefly to scattering of light in the emulsion during exposure. The density at small distances apart in a direction normal to the edge of the developed image is measured with a microphotometer. A set of such measurements with the density plotted as a function of the distance into the geometrical shadow of the image (the knife edge) results in a curve, called the sharpness curve, very similar in type to the D-log E characteristic curve of a photographic emulsion.[2] The sharpness, S, is,

$$S = \frac{dD}{dx}$$

where x is the distance in microns into the geometrical shadow of the image. This ratio is measured on the straight portion of the curve, that is the maximum gradient, which is an important fact to bear in mind. A set of sharpness values at different wave lengths for the Eastman 40 plate are given in Fig. 5 and Table 2.

Returning now to the comparison of change in resolution and sharpness in the spectral region neighboring λ535, it is seen by Figs. 3 and 5 that the minimum points of the two curves coincide, but that

[2] F. E. Ross. The Physics of the Developed Photographic Image, p. 131. Eastman Kodak Co., Rochester, N. Y. 1924.

the increase in sharpness beyond that point is much more pronounced than the increase in resolution. This is not a surprising result since

TABLE 2. *The change in sharpness with wave length of the Eastman 40 plate is given in the table below.*

Emulsion	λ	Sharpness
Eastman 40	375	0.300
	400	0.280
	425	0.160
	450	0.122
	475	0.087
	500	0.068
	525	0.048
	550	0.070
	575	0.088
	600	0.142
	625	—
	675	—
	700	0.161

the maximum rate of decrease in intensity with the distance into the shadow of the image is near the edge; and since it is this maximum gradient which determines the sharpness, it is independent of the

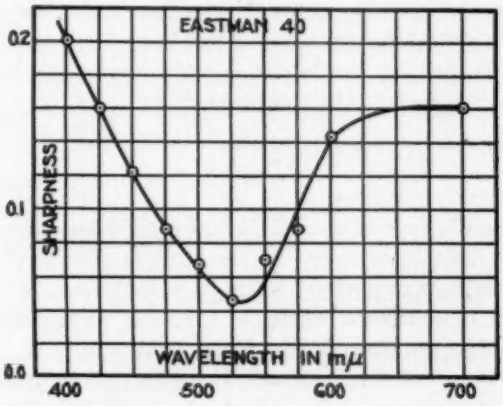

FIG. 5. *Relation between sharpness and wave length for the Eastman 40 plate.*

radiation which is scattered farther into the shadow. Resolving power, on the other hand, as has been already pointed out,[2] depends on the

total amount of radiation scattered into the region between two images to be resolved, and particularly on that which produces the lower portion, or the toe, of the curve. Now an increase in the sharpness corresponds directly to a large edge density gradient. A large edge gradient also increases the resolution; but not in a direct proportion since the latter is also a function of the density distribution in the other parts of the image. Thus it is possible to conceive of scattering and absorption conditions so that the change in resolution lags behind, or leads, so to speak, the change in sharpness. These conditions can be predetermined only by more accurate data on the absorption and scattering characteristic at different wavelengths than are now available.

Additional data are given in Table 1, columns 2, 3, 4, 6, and 7, and Figs. 6 to 10. The resolving power-wave length curves are very similar

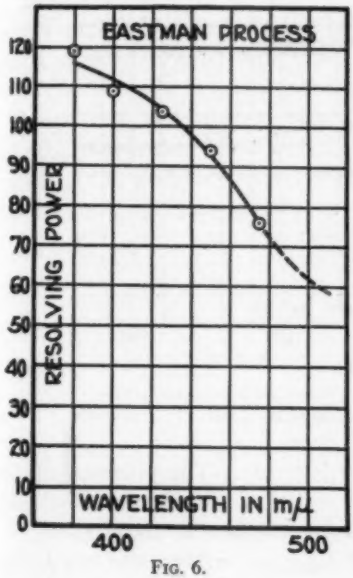

FIG. 6.

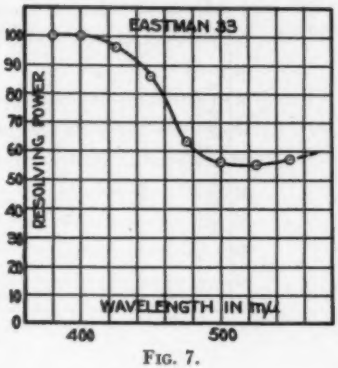

FIG. 7.

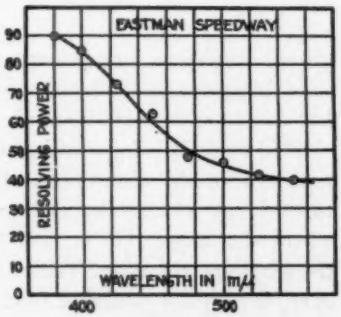

FIG. 8.

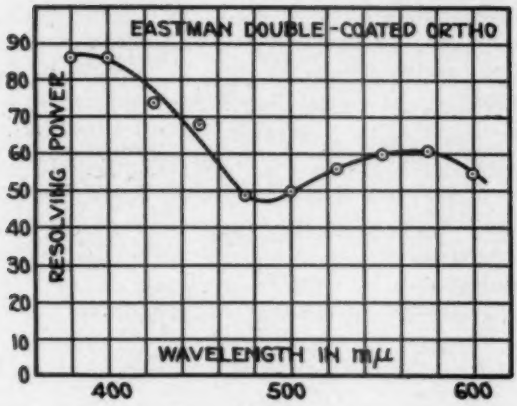

FIG. 9.

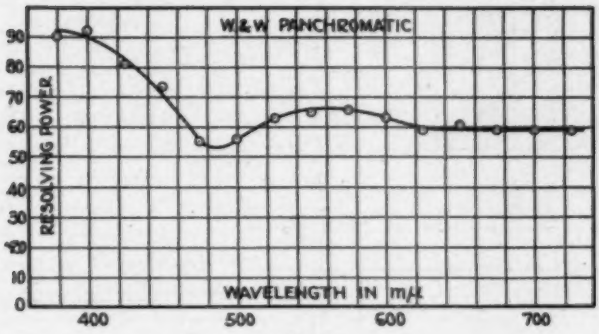

FIG. 10.

FIGS. 6–10. *Relation between resolving power and wave length for the respective emulsions indicated on the curves.*

for all emulsions containing no sensitizing dye. The presence of the sensitizing dye in the orthochromatic and the panchromatic emulsions has caused a shift of the minima towards the blue to about λ485.

This work is being continued and extended farther into the red as well as into the ultraviolet. It should prove particularly interesting to find out what order of resolution is obtainable in the ultraviolet where the absorption is very high. Judging from our knowledge of the sensitometric characteristics of an emulsion in the ultraviolet, however, it is quite probable that the resolving power is of very nearly the same value as that obtained by treating the emulsion with a dye

that has approximately the same absorption in the visible that the undyed plate has in the ultraviolet.

More data will be required before, if ever, a definite quantitative relation between wave length and resolving power can be established on a theoretical basis. With a knowledge of the resolving power extending over a wider region, and a knowledge of the absorption and the scattering characteristics over the same spectral region, it is probable that considerable progress can be made in that direction.

SUMMARY

The change in the resolving power with wave length in the spectral region from λ380 to 725 mμ has been determined for six different photographic plates.

The maximum resolution is located in the near ultraviolet and the violet.

Emulsions containing no sensitizing dye have minimum resolving power at λ535 mμ; while for the orthochromatic and the panchromatic emulsions containing dye sensitizers, this minimum is shifted to λ485.

More data are required before a quantitative relation between resolving power and wave length can be established on a theoretical basis. It is probably determined largely by the absorption and the scattering characteristics.

FEBRUARY, 1928.

THIRTEENTH ANNUAL MEETING OPTICAL SOCIETY OF AMERICA AND EXHIBITION OF OPTICAL INSTRUMENTS APPARATUS AND PRODUCTS

NATIONAL BUREAU OF STANDARDS WASHINGTON
NOVEMBER 1–3, 1928.

The thirteenth annual meeting of the Optical Society of America will be held at the Bureau of Standards in Washington, November 1–3, 1928. Judging both from the record of the previous Washington meeting (October, 1922. See Proceedings, J.O.S.A. & R.S.I. 7, pp. 59–102; January, 1923.) and the plans which are being made for the coming meeting, it is expected that this will be the largest meeting in the Society's history.

In addition to the usual program of papers contributed by members on their own initiative, it is intended to have a well balanced program of invited papers on various outstanding topics in optics.

The exhibition will be held under the joint auspices of the Bureau of Standards and the Optical Society. It will open October 31, the day before the meeting, and will be open from 9:00 A.M. to 4:30 P.M., October 31–November 3 and one evening to be designated later.

Attention is invited to the following aspects of the exhibition:

(1) Manufacturers and dealers are invited to exhibit particularly:
   (a) Recently developed instruments;
   (b) Selected instruments which they wish to especially emphasize as current exemplars of their work or which they think will be of particular interest.

There is no intention to attempt to make this exhibition a comprehensive picture of the optical industry; and it is not expected that manufacturers of extensive and diversified lines will attempt to even approximate a complete showing of their products. It is hoped that they will attempt to make their exhibits instructive and scientifically significant.

(2) It will afford an opportunity for the makers and vendors of research apparatus in optics to focus the attention of a large number of prospective purchasers on the instruments and materials which they supply. In some cases the opportunity for direct sales promotion will be of considerable value to the maker. Likewise, the opportunity to obtain directly and in a convenient manner a considerable amount of

pertinent, definite information and advice on instruments will be of value to the prospective purchaser.

(3) Individual workers who have recently developed new instruments and methods in research will find that their accomplishments can be made known much more effectively by means of an exhibit than by merely reading a paper at the meeting. Such exhibits of current progress in research are especially invited. It is hoped and expected that many who have papers on the program will supplement and illustrate these papers by exhibits of their apparatus.

A catalog of the exhibits will be published. To meet the expenses of printing, the Optical Society will collect a fee for space in the catalog from the commercial exhibitors. No fee will be charged for exhibits such as are invited under item 3 just above. Exhibitors of both classes are expected to submit suitable descriptive matter for publication in the catalog.

For further information concerning the exhibition all interested firms and individuals are invited to address:

Dr. I. C. Gardner, Chairman,
Committee on Optical Exhibition,
Bureau of Standards,
Washington, D. C.

All material to be published in the catalog of the exhibition must be in Dr. Gardner's hands not later than September 1.

Members desiring to communicate papers to the meeting will please send abstracts to the Secretary in the usual form. Address:

Prof. C. C. Bidwell, Secretary,
Optical Society of America,
Lehigh University,
Bethlehem, Pa.

All abstracts must be in the hands of the Secretary not later than September 14.

The meeting and the exhibition will be open to non-members as well as members of the Society. All interested persons are cordially invited to attend both. Non-members who desire to receive the advance program and final notices in regard to the meeting, hotel headquarters, etc., should address their requests to the Secretary not later than September 15.

IRWIN G. PRIEST, *President*

WASHINGTON,
June, 27, 1928.

The A B C of Relativity by Bertrand Russell, Harper & Brothers, New York, 1925.

In clarity and charm of exposition, Mr. Russell's book ranks with Eddington's "Space, Time, and Gravitation." Unlike so many books on relativity, it makes no pretense of explaining in words those things which cannot be treated properly except in mathematical terms. The reviewer feels that it is not quite fair to say, as the author does on page 16, that the physicist regards the physical world as real, not merely as something which human beings dream. The mere fact that the physicist can study an eclipse by the aid of photographic plates without direct intervention of the eye, certainly does not blind him to the true status of the controversy about the objective existence of an "external world." Mr. Russell shows clearly at many points his sympathy with the view that the real subject matter of physics consists in the equations representing connections between observable events whatever be the interpretation of the unobservable auxiliary quantities occurring in these equations. Still, in the earlier portions of the book he says time and again that the motion of a particle is determined essentially by conditions at the place in space-time where it happens to be, and not by any influence proceeding from bodies at a distance. The undersigned knows of no reason why a consistent theory of retarded action at a distance cannot be used to explain the facts of electromagnetism and of gravitation just as well as the field theory. Often in recent years he has referred to the view that E and H in Maxwell's equations need not represent anything having a "real" existence, in the sense that they are not essential to our description of relations between the motions and positions of material bodies. It is well to keep this viewpoint in mind when discussing a field theory, whatever be the practical advantages of that theory in computations.

Mr. Russell's illustrations of gravitational attraction, as due to "hills in space-time," are extremely apt and are well carried through. In chapter 14 he gives a refreshing definition of matter in terms of its observable effects which will do much to clarify obscurities on this subject. The last chapter deals with the philosophical consequences of the theory. He says, "The philosophical consequences of relativity are neither so great nor so startling as is sometimes thought." This viewpoint is very attractive, and Mr. Russell supports it in convincing style. It is indeed difficult to see how facts about the physical universe can throw light on metaphysical speculations, but they can certainly alter our opinions as to the value and interest of a given subject, and may even show that some problems are not worthy of the name. Let the rising generation of philosophers be warned,—the wedding of Philosophy to the twin sisters Physics and Mathematics is at hand, and Russell's book is a peal of the wedding bells.

ARTHUR E. RUARK

INSTRUMENT SECTION

A MODEL TO ILLUSTRATE THE OPERATION OF THE FOUCAULT PENDULUM

By F. E. Wright and F. H. Schloer

The Earth rotates on its axis once every 24 hours. This fact we of the Twentieth Century know to be correct; but only a few centuries ago it was held in doubt and different explanations were given to account for the daily passage of the Sun, Moon, and stars across the heavens. Much of the ancient mythology that has come down to us from past ages has to do with efforts to explain natural phenomena of this kind. Explanations by a primitive poeple are for the most part crude, but they are interesting and have a charm and fascination quite different from modern scientific demonstrations. Even in science, however, a method of approach to a problem, or a proof of a problem, may be given that compels attention and, because of its simplicity and directness and far-reaching consequences, finds universal approval and appreciation. To this class belongs the method devised by Leon Foucault in 1851 to prove that the Earth is rotating. Many other methods have been used to prove that the Earth is rotating; but from the popular standpoint none has the appeal of Foucault's method as he performed it in the Pantheon in Paris. Today the experiment in its original form is still being shown in many science exhibitions and in physical laboratories. It is attractive and convincing because, with very simple means, it enables the observer actually to see the effect of the Earth's rotation in a few minutes of time.

In his experiment Foucault suspended from the dome of the Pantheon a pendulum consisting of an eighty pound cannon ball attached to the end of a wire nearly 200 feet in length. As this pendulum swung back and forth a pointer projecting from the base of the ball traced its path over a flat disk or tray of sand. The direction of this path appeared to shift or turn slowly, like the hour hand of a clock, and to make a complete rotation in the course of about 32 hours.

Foucault proved mathematically that not only does the pendulum show the rotation of the Earth and its direction, but also that the rate of turning of the plane of vibration varies with the latitude, namely,

inversely with the sine of the latitude. Although the mathematical demonstration given by Foucault is simple, the task of visualizing just what happens is not easy because it involves relations in space; to most of us the picturing of relations in space is difficult. Experience has shown that in such cases a model may greatly aid the visualization process. For this reason and also to assist the demonstrators at the Science Exhibition at the National Academy of Sciences and National Research Council in explaining the operation of the Foucault pendulum there installed, a model has been made showing in a mechanical way how the Foucault pendulum, set up at any latitude in the North Hemisphere, rotates at a definite speed, dependent on the latitude, relative to that of the globe turning in the opposite direction. A photograph of this model is reproduced in Fig. 1; its mechanism is shown in Fig. 2.

FIG. 1. *Globe representing the rotating Earth. The small triangular piece above the slot represents the Foucault pendulum. This can be set at any latitude. Its rate of rotation relative to that of the globe reproduces exactly that of the Foucault pendulum at that latitude.*

The globe of Fig. 1 represents the rotating Earth. The small triangular piece projecting above the slot represents the Foucault pendulum and the plane in which it swings. When the pendulum is at the North Pole, its plane of vibration appears to remain stationary while the Earth rotates beneath it; actually its rate of rotation is exactly equal and opposite to that of the rotating Earth. To an observer standing on the Earth at the North Pole and unconscious of the Earth's rotation but turning with it, the pendulum appears, in its to-and-fro vibrations, to travel around the disk in a clockwise direction and at a rate equal and opposite to that of the Earth. At the Equator the pendulum continues to swing in the same plane and does not rotate or shift as the

Earth turns on its axis. At Washington the pendulum turns from right to left or clockwise, and more slowly than the rotating Earth. At points in the Southern Hemisphere the pendulum turns from left to right or counter-clockwise. In Fig. 2 the model is shown mounted at one side of the Foucault pendulum.

This experiment was suggested to Foucault by a chance observation that if a thin rod, mounted with one end in a lathe, is set vibrating like

FIG. 2. *Photograph of Foucault pendulum swinging in the rotunda of the building of the National Academy of Sciences, Washington, D. C., with small model and miniature pendulum at its side illustrating the principle of the Foucault pendulum.*

a pendulum in a plane and then the lathe is allowed to turn slowly, the plane of vibration of the rod is maintained unaltered in position in spite of the rotation of the support. Another method to show the same thing is to suspend a free swinging pendulum, like the Foucault pendulum consisting of a small weight suspended at the end of a piece of thread, to the head of an upright drill, to set the pendulum vibrating in a plane, and then to cause the drill head to rotate slowly, and thus

turn the thread and weight, whereupon the plane of the swinging pendulum remains unchanged in spite of the rotation of its bob or suspended weight. If the drill head to which the pendulum is attached is rotated too fast, the thread tends to wind up and this introduces a factor that affects the periodic swinging and eventually the plane of vibration of the pendulum.

From these experiments Foucault reasoned that if a freely swinging pendulum continues to swing in the same plane even though its point

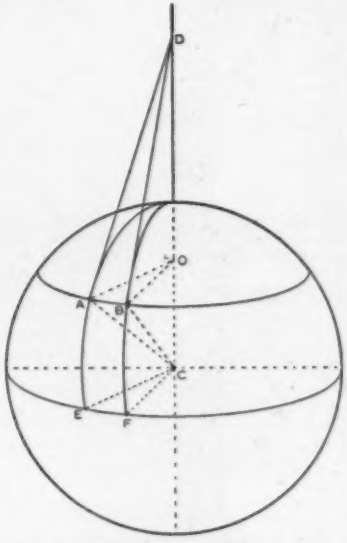

FIG. 3. *In this diagram A represents a point on the surface of the rotating Earth; DC, the axis of rotation. In a short period of time the point A travels to B and its North-South line shifts thereby from AD to BD. The angle ADB is the angle swept through by the Foucault pendulum in this time period; this angle bears a definite relation to the angle AOB or ECF, the angle swept through by the rotating Earth during this period.*

of suspension be rotated, it should do so while the Earth rotates and carries with it the entire pendulum and its support; if therefore a free swinging pendulum is set oscillating in a North-South direction it should maintain that direction in spite of the rotation of the Earth and of the shift in position of the support. Foucault found this to be the case. He reasoned further that if, at any given instant, the line marked out by the pendulum pointer coincides with the North-South line on the disk beneath the pendulum, the extension of this line would

intersect the Earth's axis at a point above the Pole, as shown in Fig. 3. In this figure let A represent the given point and D the intersection of the axis of rotation with the extension of the North-South line on the horizontal disk. A moment later the rotating Earth will have turned through the angle ECF and A will have traveled to B; the North-South line on the disk will have shifted its direction from AB to BD and moved through an angle ADB that is smaller than, but bears a definite relation to, the angle ECF or AOB swept out by the rotating Earth in the same minute of time. This shift in the direction of the North-South line is, however, the apparent angle swept out by the pendulum pointer in the opposite direction. It is not difficult to show what the relationship between the angular rotation of the Earth and the corresponding angular shift of the North-South line on the disk is. The angle indicating the turning of the Earth in passing from A to B is the angle AOB or ECF; the angle of turning of the North-South line on the disk is the angle ADB; but obviously the angle AOB is the projection of ADB on the equator. Therefore these two angles are to each other as DB to BO or inversely as the sine of the latitude. Thus in Washington (latitude 38° 56′) the disk requires 24/sin 38° 56′ or 38 hours and 1 minute to make a complete rotation under the swinging pendulum; and 6 minutes 22 seconds, instead of the 4 minutes required by the Earth, to rotate through an angle of 1°.

The shift in the direction of swing of the pendulum is due to the rotation of the Earth upon its axis and to its spherical form. Upon the surface of the rotating Earth the direction North is not a single direction or line in space; but it is the direction in which, at a given moment and at a given place, we would start to more over the spherical surface of the Earth toward the North Pole. Even while we stand still upon the surface of the Earth its rotation causes the direction, in space, of the North-South line to change from moment to moment. The line at one moment is not parallel with itself at the next moment; but the set lines pointing North converges for a given latitude, to form a cone whose vertex is located on the axis of rotation. The pendulum swinging freely in space above the rotating Earth makes this shift in direction perceptible. If, at the beginning of a swing, the pendulum should start to move exactly toward the North, before the end of the swing the rotation of the Earth will have carried the whole system eastward where the direction, in space, of the North-South line is slightly different. In effect the pendulum moves in the same direction in space

in which it started, while the North-South line on the Earth twists around beneath it.

The same reasoning holds true for any other direction of vibration of the pendulum. The plane, in which the pendulum swings, passes through the center of the Earth; the trace of this plane on the Earth's surface is a great circle. This plane at a given instant makes a definite angle in space with the N-S direction or meridian plane. A moment later, however, the Earth has rotated through a small angle and the new N-S direction is no longer the original direction of reference, but includes a small angle with it. Referred to this new direction, as indicated by the N-S line on the dial, the plane of vibration has apparently turned through a small angle. This apparent shift in angle results because the N-S-direction which we consider to be our direction of reference, is actually shifting its position in space at a constant rate depending on our position on the Earth's surface. Except for the fact that the Earth carries the pendulum and its support along with it and hence shifts the plane of vibration, but does not rotate it, the apparent turning of the plane of the pendulum is due to the constant shift, in space, of our N-S direction of reference, caused by the Earth's rotation. The fact that we are carried along with the Earth and fail to realize that the N-S line or any other line that we adopt as line of reference when we consider direction, is not a constant direction, but is constantly shifting its position in space with the rotation of the Earth, is the source of our difficulty in visualizing the action of the Foucault pendulum.

Viewed from another standpoint we consider a point to be due East of, say, Washington if its latitude is the same as that of Washington. True East at any point is normal to the N-S direction or meridian; in space this direction East for Washington is not East for Columbia, Missouri which has approximately the same latitude. When we travel due East we do not, except along the Equator, follow the same direction in space but are constantly shifting direction; the amount of shift in direction depends on the parallel or small circle of latitude that we follow. This is well recognized in sailing; the shortest distance from one point to a second point, due East of it, is not along the parallel of latitude, but along a great circle passing through the two points. For example if we wish to travel by the shortest line from Columbia, Mo. (Latitude 38° 56′, Longitude 92° 19′W) to Washington, D. C. (Lat. 38° 56′, Long. 77° 04′W) our initial compass course in starting from Columbia would not be due East, but N 84° E approximately. To

maintain our course on this great circle it would be necessary to change our compass bearing from time to time.

Returning now to the Foucault pendulum, if we trace all swings of the pendulum upon a horizontal dial beneath it, we find that in the Northern Hemisphere the path of each successive swing has moved a little in a clockwise direction with respect to the preceding swing.

FIG. 4. *Photograph of driving mechanism of model illustrating the action of the Foucault pendulum.*

The model (Figs. 4 and 5) illustrating the operation of the Foucault pendulum is made from a 8-inch commercial globe mounted on an axis. The globe was first cut in half along the equator; the mechanism for rotating the globe and the pendulum were then mounted inside the sphere. The driving unit is a small electric motor, made especially for use in aeronautical instruments; it turns the globe around once every 15 seconds. This motor was furnished to the National Academy of Sciences through the courtesy of the National Advisory Committee

for Aeronautics. It is operated by a small 6-volt storage battery. The Foucault pendulum model is driven at the proper relative speed inversely proportioned to the sine of the latitude, by means of a friction wheel pressing against a central fixed hemispherical cam of the same diameter. A gear on the axis of the disk friction wheel is connected by

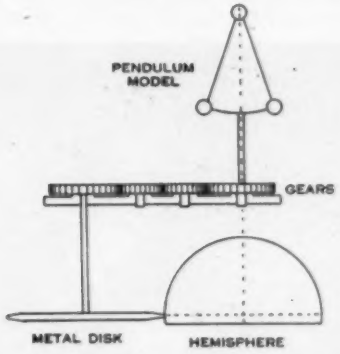

FIG. 5. *Diagrammatic sketch showing hemispherical cam, metal disk rolling over cam, and gears transmitting motion of disk to Foucault pendulum model. In this sketch the Foucault pendulum is supposed to be at the North Pole.*

means of an idling gear to a gear on the axis of the radially mounted axis of the Foucault pendulum mount.

Experience with the model as an aid in demonstrating the operation of the Foucault pendulum has shown that it does serve a useful purpose and greatly facilitates the explanation of the principle on which the Foucault pendulum is based. A simple pendulum suspended to the base of the model and connected to the rotating mechanism by a gear demonstrates the fact that the plane of vibration of the pendulum in maintained constant even though its support is rotated.

GEOPHYSICAL LABORATORY,
and NATIONAL ACADEMY OF SCIENCES,
WASHINGTON, D. C.

AN ADJUSTABLE THERMOSTAT

By Bradford Noyes, Jr.

Perhaps the most satisfactory devices for sensitive high temperature thermostats have been developed by workers at the Geophysical Laboratory in Washington. In 1919, White and Adams[1] described a Wheatstone bridge arrangement in which one arm of the bridge was the heating coil of the furnace. Roberts[2] has refined and elaborated. The apparatus of White and Adams required direct current, while Roberts adapted the apparatus to alternating current by means of two rectifiers. Adams[3] further refined the apparatus by the addition of a vacuum tube operating as a relay. Roberts[4] has given a very complete description of the apparatus, with information as to the relays used, the design of a suitable rectifier, and other valuable information.

Some time ago a particular application in the laboratory called for a control which was more sensitive than the ordinary commercial control. It was desired to build this instrument out of parts already available or which could easily be obtained. For several reasons it was thought that the apparatus developed at the Geophysical laboratory was not suited for the particular use. The apparatus as finally assembled consisted of the following: thermocouple, potentiometer, photoelectric cell, vacuum tube, two relays and several slide resistances and batteries. The thermojunction is mounted in the center of a furnace, wound so as to give approximately uniform temperature. The selection of material for thermocouple depends entirely upon the range of temperatures. Up to 650°C a copper-constantan junction is satisfactory, while above this temperature a platinum-platinum rhodium junction is more suitable. The cold junctions are kept in ice in a Dewar flask. At first a metal vacuum jar was used, and it was necessary to refill with ice each day. Later a silvered glass Dewar flask of the same capacity was substituted, and it is now necessary to refill only every two weeks.

The operation can be seen from Fig. 1. It is necessary to bring the furnace to the desired temperature before the regulator operates.

[1] Phys. Rev., *14*, 45–48; 1919.
[2] J.O.S.A. and R.S.I., *6*, pp. 965–977; 1922.
[3] J.O.S.A. and R.S.I., *8*, pp. 599–603; 1924.
[4] J.O.S.A. and R.S.I., *11*, pp. 171–186; 1925.

Wires from the cold junction run in to a Wolff Potentiometer (15,000 ohms) located in another room. The thermal emf. is balanced on the potentiometer. Connected to the potentiometer is a Leeds and Northrup Type R galvanometer, with a $\frac{1}{2}''$ mirror. Light from a ribbon filament lamp, 108 watts, passes through the condensing lens and is reflected by the galvanometer mirror to a photoelectric cell. The cell available was made by the Case Laboratories in September 1919, and its subsequent history is unknown. It is enclosed in deep ruby glass, which considerably reduces the sensitivity, thus requiring a more intense source of illumination. The amplification and relay circuit is shown in Fig. 2. The vacuum tube used was a U. V. 199. It is not

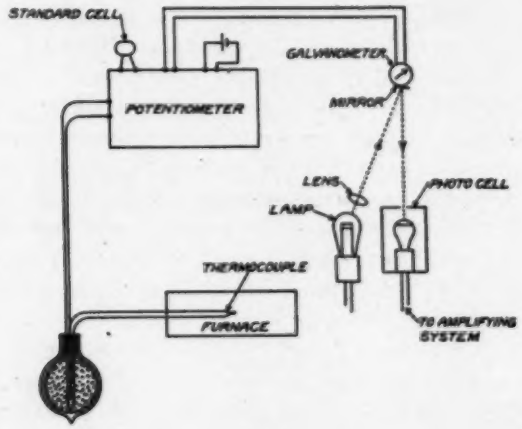

FIG. 1

necessary to run the filament at its rated current to obtain the maximum rated plate current, and the original tube has continued to give satisfaction. The most suitable grid resistance is found to be about twenty-five megohms. In originally setting up this circuit considerable time was wasted and trouble was experienced because this resistance was not of proper size.

Three relays are used in the present arrangement, two galvanometer relays manufactured by a well known concern, and one polarized relay manufactured by the Central Scientific Company. At first only one galvanometer relay was used, but as considerable trouble was experienced with the contact points sticking, two were placed in series. Although the voltage and current necessary to operate the Central

Scientific Company relay are well below the rated capacity of the galvanometer instruments, the sticking of the latter remains a source of continual annoyance. The Central Scientific Company relay makes contact when no current is flowing through the coils. Hence, the apparatus may be arranged so that when the light falls on the photoelectric cell, the plate current of the vacuum tube causes the galvanometer relay to open the primary circuit of the Cenco relay, thus increasing the current in the furnace by shorting resistance *B*.

Several other arrangements were tried. One such consisted of two photoelectric cells, one throwing the resistance in, the other throwing it out. Another arrangement was such that the galvanometer light

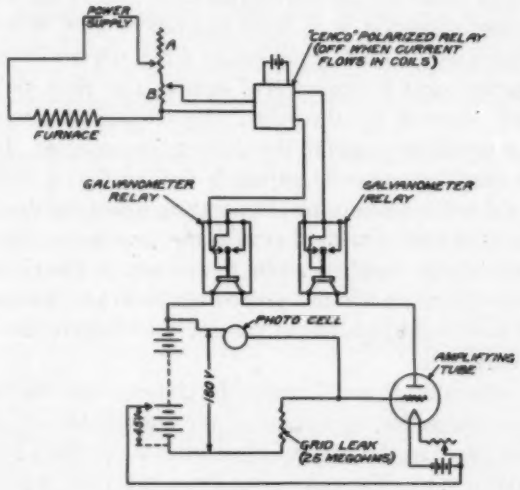

FIG. 2

decreased rather than increased the energy supplied to the furnace. The arrangement described in detail above proved most satisfactory chiefly because the usual accidents which might be anticipated would decrease the temperature in the furnace rather than cause it to overheat. Among these anticipated failures may be listed: (1) failure of vacuum tube, (2) burning out of galvanometer light, (3) failure of photoelectric in all ways except increase of dark current, (4) sticking of galvanometer relay points.

This system has one disadvantage. Once the temperature falls so that the galvanometer light has entirely passed over the cell the system

will no longer regulate. The furnace must be brought to proper temperature manually. In one of the systems mentioned above (where the galvanometer light on the cell decreased rather than increased the current) the apparatus will come to the proper temperature automatically. However, in case of failure of cell, vacuum tube, or galvanometer light, an over-heating results.

The accuracy of the control obtainable depends upon a number of factors, chief of which is the constancy of the 110 volt supply line. Unfortunately, in the laboratory the supply varies by more than fifteen per cent. During working hours the plant generator supplies the energy, but at night power is taken from the city supply line, the voltage of this latter being about ten per cent higher than that of the plant generator. The ideal condition is to have resistances $C + B$ so adjusted that the furnace would reach equilibrium a few degrees below the desired temperature; and resistance B of such a value that when it is out of the circuit, shorted by the relay, the temperature would reach equilibrium a few degrees above the desired temperature. In our own case, it was found necessary to adjust $B + C$ so that a 20% increase in power would still maintain the temperature below the desired point, and C had to be of such a value that with the decrease in voltage in the day time, the energy supplied when B was not in the circuit would still be sufficient to maintain the desired temperature. In spite of this handicap, it was found possible to control the temperature to within one degree centigrade.

With the values of B and C properly chosen, one source of error remains,—the fluctuation in voltage of the storage battery supplying the potentiometer. In the present apparatus a two volt, 110 ampere hour Exide cell is used. The cell is over three years old but is perfectly satisfactory. It is necessary to be sure that room temperature does not vary excessively. The potentiometer requires only one tenth milliampere, and after the cell has come to equilibrium it is necessary to check on the standard cell only once in several days.

The entire apparatus is capable of a number of refinements. At the present time, a system is being prepared which it is hoped to operate entirely on alternating current, with the single exception of the potentiometer. By substituting a more powerful amplifying tube for the one used, it is planned to do away with the galvanometer relays, operating a suitable relay, direct from the vacuum tube. The galvanometer is at present shunted so as to be approximately critically damped. A more sensitive galvanometer could well be used, and there is nothing

to be gained by damping it. The limiting factor would generally appear to be the constancy of the voltage or, in other words, the precision with which B and C may be adjusted.

The apparatus has been in operation for several months and with the exception of the failure of the relays mentioned above, no trouble is experienced. One advantage of the arrangement is the ease with which the regulating temperature may be changed, a different setting of the potentiometer being all that is necessary.

TAYLOR INSTRUMENT COMPANIES,
ROCHESTER, N. Y.

A high potential battery substitute. When one needs a source of high potential that is very constant as for example for the operation of a Geiger point counter, a simple and economical apparatus such as described herein, which will satisfy this need, may be set up out of apparatus found around any physical laboratory.

This apparatus is a simple Kenetron rectifying circuit, in which ordinary radio tubes are used instead of the more expensive Kenetron tubes. To step up the alternating current in the circuit one may use almost any step-up transformer such as a $\frac{1}{4}$ K. W. spark transmitting transformer or even a spark coil. Five watt power radio tubes are best to use as rectifiers although ordinary amplifying tubes may be used. The insulation of ordinary amplifying tubes is inferior to that of the power tubes and sparking sometimes occurs between the lead wires at the place where they are sealed through the glass.

It is essential that the grid and filament of each tube be connected together, otherwise the electrostatic force on the filament may be great enough to destroy it. The filaments must be heated by two separate and insulated storage batteries. Sufficient insulation of these batteries is obtained by setting the batteries on pieces of glass.

The constancy of the "output" voltage of the rectifier depends upon the capacity in parallel with the rectifying tubes. For the operation of a Geiger point 0.1 mfd condensers are suitable. It is obvious that very little power may be drawn from this rectifier because of the limited capacity of the radio tubes. With this rectifier as a source of potential difference a Geiger point counter, such as described by Wülf (Physikalische ZS., *26*, p. 382; 1925) can be made to operate continuously for hours which makes it a more valuable apparatus for experiments and lecture demonstrations.

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A NOTE ON METHODS OF RAPIDLY ADJUSTING A RADIO FREQUENCY OSCILLATOR IN SMALL STEPS OF FREQUENCY*

By J. K. Clapp

ABSTRACT

Simple and rapid methods for adjusting the frequency of a radio frequency oscillator in small steps of frequency by aural methods are described. By use of the n^{th} harmonic of the radio frequency oscillator the steps of frequency may be made $1/n$ times a convenient fixed audio frequency, such as that of a tuning fork. By elaboration of the equipment the adjustments may be made to within $1/n$ cycles per second, where n is the order number of the oscillator harmonic employed.

I. A SIMPLE AND RAPID METHOD OF MODERATE PRECISION

In the study of resonance in very sharply tuned circuits, the amplification obtained in highly selective amplifiers and similar problems, it is necessary to be able to adjust the driving oscillator in small steps of frequency with reasonable accuracy. If such measurements are attempted when using an ordinary wavemeter for frequency measurement, the precision of the settings is very poor, as it is very difficult to measure small differences in frequency with such an instrument.

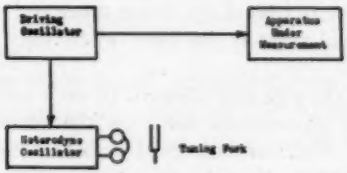


Fig. 1. *By means of the heterodyne and tuning fork, it is possible to adjust the driving oscillator to successive frequencies differing from each other by 1/n times the tuning fork frequency where n is the number of the driver harmonic which is used to produce beats in the heterodyne. The accuracy is only moderate,—within 5 cycles per second, approximately.*

By making use of a heterodyning oscillator (hereafter referred to as the "heterodyne," for brevity) and a tuning fork, it is quite simple to adjust the driving oscillator (referred to later as the "driver") in fairly small steps of frequency with good precision. The arrangement of equipment is indicated in Figure 1, the heterodyne being coupled by any

* Contribution from the Round Hills Radio Research, sponsored by E. H. R. Green.

convenient means to the driver. In any ordinary driving circuit, the harmonic content of the output current is sufficiently great so that audible beats may be obtained between successive harmonics of the driver and the fundamental frequency of the heterodyne. If the harmonic amplitudes are not great enough to produce audible notes of suitable intensity with a simple heterodyne, an audio frequency amplifier may be added to the heterodyne circuit.

The process of making the adjustments is carried out as follows: With the driver adjusted to a desired initial frequency, obtain an audible beat between the heterodyne fundamental frequency and the desired harmonic of the driver. Adjust the heterodyne fundamental frequency so that it is either higher or lower than that of the driver harmonic frequency, depending upon whether the driver is to be adjusted to higher or lower frequencies. Next adjust the audible beat note to a definite frequency, by varying the fundamental frequency of the heterodyne, and obtaining zero beat between the audible beat note and the tuning fork, or other source of known audio frequency. If a telephone headset is used, the beats between the audible tone and the tuning fork may be readily obtained by holding the vibrating fork near the ear. When this adjustment has been made, the fundamental frequency of the heterodyne differs from the frequency of the Priver harmonic by the known frequency of the tuning fork.

Having completed this initial adjustment, the frequency of the driver fundamental is now altered, toward the higher or lower value desired. This alteration in frequency will bring the audible beat tone to a lower frequency, and if continued will eventually bring the audio beat frequency to zero. The fundamental of the driver has then changed from the initial frequency by an amount.

$$\Delta F = f/n \text{ cps} \tag{1}$$

where ΔF = change in driver fundamental frequency,

f = frequency of fork,

n = order number of driver harmonic used to obtain the audible beats.

As an example, take the case of a 30,000 cps. driver; making use of the 10th harmonic and a 500 cycle tuning fork, the driver frequency may be changed by steps of 500/10, or 50 cps. (0.17 per cent).

These small changes in the driver fundamental may be made quite accurately, even though the adjustments are carried forward only by "zero" audible beat. In the example above, the audio beat is readily

adjusted to 500 ± 1 cps. Adjustment of the driver harmonic frequency so that zero beat is again obtained may be readily made to $(30{,}000 \times 10) \pm 50$ cps. For the fundamental this becomes $30{,}000 \pm 5$ cps., or in percentage terms, steps of 0.17 per cent in frequency may be made with an error of approximately 10 per cent per step. If a higher frequency tuning fork is employed, the relative error of setting the driver fundamental frequency to successive values is correspondingly reduced.

II. SIMPLE AND RAPID METHOD OF HIGH PRECISION

If a sensitive galvanometer is employed in the output of the heterodyne, in conjunction with the telephones, for indicating zero beat, the frequency settings may be made with a high degree of precision. If the adjustment is made so that the galvanometer swings from maximum to minimum and back again in one second, the heterodyne frequency then differs from the driver harmonic frequency by one cycle per second. In the example given above, then, the change in driver fundamental frequency is made to the nearest cycle for the 10th harmonic, or to the nearest 1/10th cycle for the fundamental. The driver may then be adjusted in successive steps of 50 cycles per second, with an approximate error of 0.1 cps. per step, or 0.2 percent.

III. AN ACCURATE METHOD REQUIRING NO GALVANOMETER

If two heterodynes are provided, it is possible to carry forward the adjustment of the driver frequency with about the same accuracy as when the galvanometer is employed, while depending only upon adjustments made by means of telephone receivers, as follows:

Method A. The procedure is identical with that given under I above in so far as the adjustments of the driver and heterodyne frequencies are concerned. The present method provides a simple means of indicating the zero beat adjustment between the driver harmonic and the heterodyne fundamental. An auxiliary heterodyne is brought into play,[1] in order that a tone may be heard in the telephones at all times that the adjustments are being made. This auxiliary heterodyne should be coupled to the first heterodyne so that an audible beat tone is obtained, but the frequency of this beat tone is of no consequence in making the measurements. The auxiliary should be adjusted simply to give a tone of such a pitch as to be easily heard. It will be found that when the

[1] Editor's Letter. "A Modified Beat Method of Comparing Two High Frequency Oscillations" Exp. Wireless and Wireless Eng. Mar. 1927.

driving oscillator harmonic frequency and the auxiliary heterodyne frequency are impressed on the first heterodyne, a note will be heard in the output whose intensity varies periodically, waxing and waning at a frequency corresponding to the difference in frequency between the driver harmonic and the fundamental of the first heterodyne. This waxing and waning is easily regulated to a cycle per second, yielding the same accuracy for the driver adjustment as II above, but with the simplicity and rapidity of adjustment which is characteristic of adjustments made entirely by ear.

Method B. If the auxiliary heterodyne is adjusted so as to produce a difference in frequency with the first heterodyne equal to the fork frequency, f, the frequency adjustments of the driver may be made at intervals corresponding to $f/2n$ instead of f/n as above, or, if

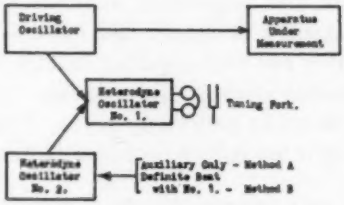

Driving Oscillator
Apparatus Under Measurement
Heterodyne Oscillator No. 1.
Tuning Fork.
Heterodyne Oscillator No. 2.
Auxiliary Only - Method A
Definite Beat with No. 1. - Method B

FIG. 2. *When the two heterodynes are employed, as indicated above, it is possible to adjust the driving oscillator in steps of frequency differing from each other by 1/n or 1/2n times the tuning fork frequency, with an accuracy of 1/n cycle per second, where n is the order number of the driver harmonic which is used to produce the beats in the heterodyne.*

intervals of f/n only are desired, then a fork of frequency $2f$ may be used.

The initial adjustment of heterodyne No. 1, to beat zero with the desired harmonic of the driver is carried out as in I. The driver is then stopped, and heterodyne No. 2 is started. The fundamental frequency of this second heterodyne is adjusted so that a beat tone of the fork frequency is obtained in the output of No. 1, zero beat between the fork and the beat tone being obtained as previously described. The driver is again placed in operation, with the result that a waxing and waning of the tone heard will be obtained, unless the harmonic frequency of the driver corresponds exactly to that of the first heterodyne. The driver fundamental is now varied, so as to change the frequency of the harmonic used from that of heterodyne No. 1, toward that of heterodyne No. 2. As this change is made, it will be seen that

the audio beat produced between the driver harmonic and the fundamental of heterodyne No. 1 will be rising from zero toward the fork frequency, while the beat produced between the driver harmonic and the fundamental of heterodyne No. 2 will be descending from the fork frequency toward zero. When the driver frequency has been altered by an amount such that the beats between its harmonic and the frequencies of the two heterodynes are nearly equal, it will be found that a waxing and waning tone of approximately one half the fork frequency is heard. By bringing the frequency of the waxing and waning to zero, the harmonic frequency of the driver has been adjusted to be just midway between the fundamental frequencies of the heterodynes. Continuing the change in driver fundamental frequency, it is found that as the harmonic frequency approaches that of the fundamental of the second heterodyne, the beats thereby produced approach zero, while the beats produced with the first heterodyne approach fork frequency. The waxing and waning again becomes evident and when the harmonic frequency of the driver has been adjusted exactly to that of the second heterodyne, the waxing and waning disappears.

Following the example previously given, if the frequency of the waxing and waning is brought in each case to one cycle per second, or

TABLE 1. *Table of driver frequencies obtainable by successive settings of two heterodynes, having a constant difference in frequency*

Initial frequency 30,000 cps.
Fork frequency = f = 500 cps. = difference frequency.
Harmonic number = n = 10

Heterodyne No. 1	Heterodyne No. 2	Successive driver Harmonic frequencies Error 1 cps. approx.	Successive driver Fundamental frequencies Error 0.1 cps. approx.
300,000	300,500	300,000	30,000
No. 1		300,250	30,025
changed to		300,500	30,005
301,000	300,500	300,500	
	No. 2	300,750	30,075
	changed to	301,000	30,100
301,000	301,500	301,000	
No. 1		301,250	30,125
changed to		301,500	30,150
302,000	301,500	301,500	
	No. 2	301,750	30,175
	changed to	302,000	30,200
	302,500		
		etc.	

less, then the driver fundamental frequency is changed by 25 ± 0.1 and 50 ± 0.1 cycles per second respectively for the two zero beat adjustments described in the last paragraph.

Having varied the driver fundamental frequency through these two steps, it is then necessary to re-set one of the heterodynes. This should be the first heterodyne, whose frequency should now be varied past that of the second heterodyne until a difference of frequency between the heterodynes equal to the frequency of the fork is again established. The driver fundamental may then be adjusted through two more steps, and then further by repetition of the process. The example is carried forward through several steps in the accompanying table.

Communication Laboratory,
Massachusetts Institute of Technology,
Cambridge, Massachusetts.
January 9, 1928.

FREE FALL APPARATUS, NEWTON'S SECOND LAW OF MOTION

By Peter L. Tea*

ABSTRACT

This paper describes a new piece of apparatus for obtaining an accurate table of time and distance of a freely falling body; by the use of counterweights, the device serves as an accurate Atwood machine to check Newton's Second Law of Motion.

It was the desire to obtain, for classes of beginners in physics, experimental data from which to deduce the laws of falling bodies, and data to verify Newton's Second Law of Motion, that resulted in the development of the apparatus to be described. For individual experimental work the apparatus must be simple, rugged; it must yield a table of distance fallen from *rest* with corrseponding time. Thus the starting, or zero point, the apex of the parabola, must be accurately determined. If this point is not well defined, the discussion of the results is no longer simple and direct, and is not suitable for beginners. The method of differences, with the assumption of the very law to be determined, is resorted to. Advanced students will do this without a murmur; they have taken the laws of falling bodies, and the fundamental Newton's Second Law, for granted in their first course.

As far as the writer can ascertain, the accurate determination of the zero point is not embodied in any existing apparatus.

The salient features of our apparatus are:

1—Simple, easily operated; delicate manipulations are eliminated; simple to understand.

2—Particularly suitable for beginners in physics.

3—The starting, or zero point, is accurately determined, simplifying the discussion of the results.

4—Tests can be duplicated to .001 second for each point, as can be checked by superposing duplicate records.

5—A permanent record is obtained for each experiment, Figs. 2, 4, which forms part of the student's report.

6—The method of the research worker is followed: from the record, the table of s and t is drawn up and discussed, leading to plotting on co-ordinate and on log log paper, figs. 2, 3, 4, and thence to the laws.

* Instructor, College of the City of New York.

7—Suitable for lecture room work. The record can be reflected on the screen, and the angles of time can be read off by the class. A transparent paper protractor is placed on the record.

8—Suitable for individual or group laboratory work.

9—Compact; all contained in a box 16″ x 9″ x 9″.

DESCRIPTION AND OPERATION

The turntable T, Fig. 1, is operated by a special spring motor with governor, and runs at a remarkably uniform speed, as is evidenced by the superposability of duplicate records. This turntable carries the

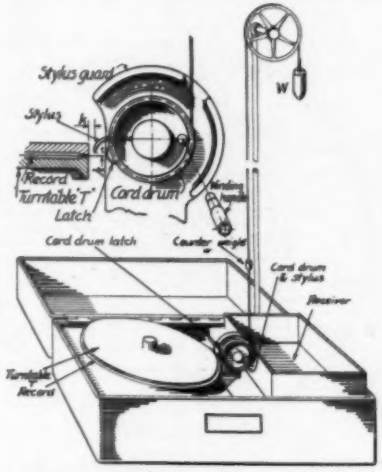
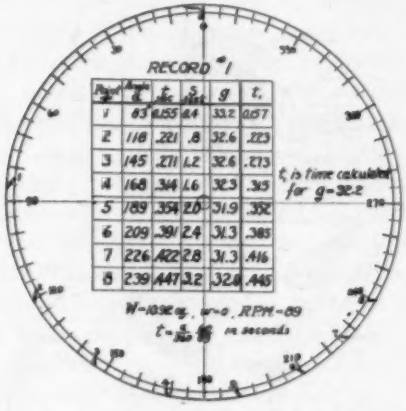


FIG. 1. *Perspective and detail of the apparatus.*

record, of paper, held down by cover of suitable weight. The turning record is the carrier of the time; it is in fact a clock and its R.P.M. can be quickly determined by counting the number of turns of a strip of paper on T, per minute. The weight W is wound up by turning the cord drum by means of the handle shown, and the cord drum is held fast by means of a latch, so that the stylus is within one thirty-secondth of an inch from the record. On releasing the cord drum latch, the cord snap causes the cord drum to travel the one thirty-secondth of an inch many times faster than due to gravity; the velocity of the cord drum, which has a very low effective mass, is damped by the cutting of first slit in the record, point No. 0, or zero point.

A fine cord is used, and the diameter of the cord drum, one and one half inches, is uniform, so that the distance fallen is the same between successive slits. This distance is determined by winding up the weight to just hang free, the cord drum is then latched. The height of W is measured from some stable point. The W is then wound a total of eight turns, and the height measured again, whence the unit distance is determined.

The weight receiver serves to catch the weight; a layer of one and one half inches of fine sand, with no dust, or small lead shot serves as a very good damper. The weight does not bounce; but merely imbeds itself slightly, and remains upright, if, on release, it is not swinging.



1	63	.155	.04	33.2	.057
2	118	.221	.8	32.6	.223
3	145	.271	1.2	32.6	.273
4	168	.314	1.6	32.3	.315
5	189	.354	2.0	31.9	.352
6	209	.391	2.4	31.3	.383
7	226	.422	2.8	31.3	.416
8	239	.447	3.2	32.8	.445

FIG. 2. *Free fall record and table. Actual dia.* 6½".

A damper of this nature is necessary to prevent extra, accidental marks to appear on the record.

Referring to Fig. 2, the times to fall 4 units and 8 units are double, respectively, the times to fall 1 and 2 units. This indicates the square law of time, leading to the discussion of uniform motion and of uniform acceleration. By plotting the results on co-ordinate paper, the mean velocity can be calculated in the neighborhood of each of the eight points, and the velocity can be plotted with the time, whence the change in velocity with the time can be determined, and plotted. For more advanced students, plotting on log log paper is advisable.

Used with counterweights, as an accurate Atwood machine, Fig. 4, Newton's Second Law of Motion can be verified.

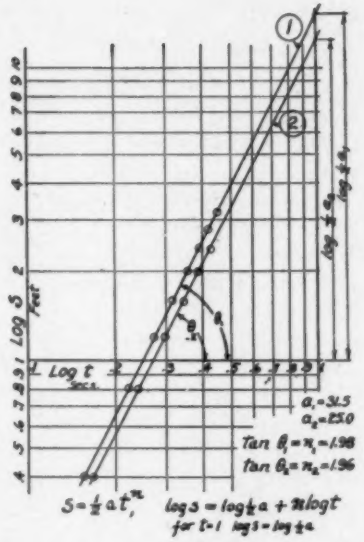
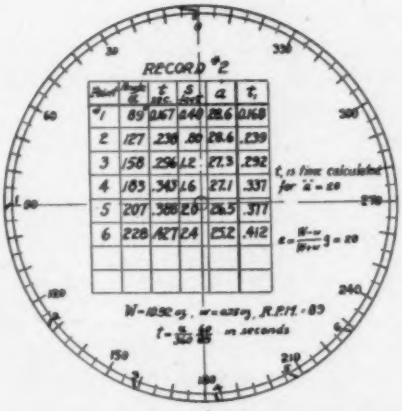


FIG. 3. *Records 1 and 2 plotted on log log paper.*



Record	Length S	t sec.	S feet	a	t_1
#1	89	.267	.040	28.6	.0168
2	127	.238	.80	28.6	.239
3	158	.296	1.2	27.3	.292
4	183	.343	1.6	27.1	.337
5	207	.388	2.0	26.5	.377
6	228	.427	2.4	25.2	.412

t_1 is time calculated for a = 28

FIG. 4. *Record using counterweight; accurate Atwood machine.*

Our machine is designed with very low effective mass of cord drum and pulley at the cord radius. These masses can thus be neglected.

THE ZERO POINT

The effect of the distance h of the stylus above the record, Figs. 1, 5, would be considerable if the cord were not elastic.

The distance fallen between slits 0 and 1 would be independent of h, and would equal one turn of the cord drum; but W has developed a velocity v_0 in falling through h. This would result in an error in the time of the zero point.

$$\left.\begin{aligned} s &= v_0 t + \tfrac{1}{2} a t^2 = 0.4 \text{ foot} \\ v_0 &= \sqrt{2ah} \\ a &= \frac{M}{M+m} g = 31.6 \\ Mg &= W \end{aligned}\right\} \quad (1)$$

where m is the combined effective mass of the cord drum and pulley at the cord radius, 2% of M.

The theoretical time of fall of 0.4 ft. is 0.157 seconds; from eq. 1 we would obtain 0.147 seconds, an indicated error of 0.01 second.

The apparatus does not admit of setting h at less than one thirty-secondth of an inch, without scratching the record and destroying the uniformity of the motion of the turntable, and besides the cost would be too great to eliminate entirely the wobble in the turntable.

The use of the snap in the cord on releasing the weight, serves not only to nullify the effect of h, but to nullify the effect of more wobble than exists in the apparatus.

The elastic energy stored in the cord is $1/2eMgl$, (2)
where l is the elongation of the cord of length L, e is the resilience or efficiency factor. The average tension is $1/2eMg$, which is 25 times the value of mg.

$$mA = \frac{1}{2} eMg \qquad A = \frac{1}{2} e \frac{M}{m} g \quad (3)$$

thus the acceleration given to the cord drum and pulley is, for $e = 1$, 25 times g, the acceleration of gravity, which is sufficient to overcome the usual slow initial motion of bodies. The distance h is covered in negligible time. This high velocity of the very light masses involved represents very little energy; this energy is effectively damped out when

the stylus cuts the point No. 0; the cutting of this first slit is at the expense of the energy in the cord, and does not retard the weight W. A proper choice of cord and record paper must be made, so that the snap may be sufficient and that the damping should be neither too great nor too small.

A more accurate determination of the relations as this initial acceleration takes place, may be of interest. The initial position of a point of the cord near the cord drum is $x=l$ and the final $x=0$; for a point of the cord near W, $s=0$ initially, $s=s$ at the end of the period of stretch.

$$\begin{aligned} &x=l, && T=Mg, && t=0 \\ &s=0, && T=Mg, && t=0 \\ &x=0, && T=0, && t=t_1 \\ &s=s_1, && T=0, && t=t_1 \end{aligned} \tag{4}$$

$$m\frac{d^2x}{dt^2}+T=0 \qquad T=Mg\frac{x}{l} \tag{5}$$

$$x=l\cos Bt \qquad B=\sqrt{\frac{Mg}{ml}} \tag{6}$$

$$v=-lB\sin Bt$$

when $x=0 \quad t=t_1=\frac{\pi}{2}\frac{1}{B}$

The time required to fall $h=\frac{1}{32}''$ is obtained by substituting $x=l-\frac{1}{32}''$ changed to feet. For $l=\frac{1}{4}''$

$$t=.002 \text{ seconds}.$$

The actual fall between points No. 0 and No. 1 is, due to the contraction of the cord, 0.4 feet $-(l-\frac{1}{32})/12$, but this effect is negligible. The cord is slightly slack at the end of the cord snap, W having remained practically still.

ELASTIC EFFICIENCY

We will not take up space to show the detailed tests made to arrive at a suitable cord; but will mention some interesting results noted. The static loop of force and elongation, showed up with considerable area for small extreme loads. While practically the same large loop remained, for larger values of extreme loads, it practically superposed on the smaller loop, the two curves, outgoing and return, practically coinciding thereafter. Thus there is a sudden jump in efficiency. The

dynamic loop follows the static loop fairly well, even though there is more or less creeping observable in the latter.

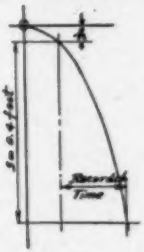


FIG. 5.

FIG. 6.

FIG. 7.

The efficiency was obtained under dynamic conditions, Fig. 7, by burning the thread, the small mass $m=0.1$ ounce; the cord will snap m vertically upward to a height H.

$$T-mg=m\frac{d^2x}{dt^2} \tag{7}$$

The work of elastic form given up by the cord to the mass m is

$$\int_0^l (T-mg)dx=m\int_0^t \frac{d^2x}{dt^2}\frac{dx}{dt}dt=m\frac{v^2}{2} \tag{8}$$

$$T(\text{average})=\frac{m}{l}gH+mg \tag{9}$$

This is the experimental value of T (average).

If the efficiency were 100% the average elastic force would be $\frac{1}{2}$Mg whence the efficiency may be calculated.*

College of the City of New York,
New York, N. Y.

* This apparatus is manufactured by The Scientific Apparatus Co.

A VACUUM GRATING SPECTROGRAPH FOR ULTRAVIOLET AND SOFT X-RAYS

By Jean Thibaud

We know what difficulties stopped, for a long time, all progress in the measurement of the wave lengths of rays lying between Millikan's ultraviolet and Röntgen spectra, viz.: much too small lattice constant of crystal gratings used for x-rays and much too big line spacing of ruled gratings, used in optical apparatus. Recently, some people have succeeded in using certain crystal stratifications of peculiarly high lattice constant. It seems, though, that this way of proceeding gives the lines a diffuse aspect and such a width that the accuracy of the measurements is much lessened.

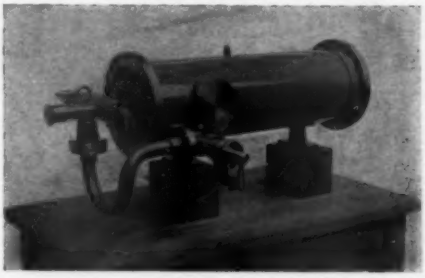


Fig. 1. *Vacuum spectrograph.*

In the course of researches in progress since 1925, I have tried to perfect the new method (as described by me in various former publications) based on the use of ruled gratings under very high glancing angle, nearing 90°, which is particularly suitable for high resolving power. I have since endeavored to apply the method to the study of the spectral region between x-rays and the ultraviolet.

I obtained at once x-ray spectra ($K\alpha$ and $K\beta$ of iron and copper) by use of glass ruled gratings with 200 lines per mm.[1] I showed then[2] the possibility of extending the tangential grating method

[1] Academie des Sciences, December 21, 1925, Comptes Rendus January 4, 1926. See Fig. 5, upper figure.

[2] Revue d'Optique, *5*, p. 105; 1926.

from x-ray to ultraviolet spectra and in this paper, I published, after a description of the vacuum spectrograph, a reproduction of an ultraviolet spectrum (carbon spark). Next, I obtained results[3,4] in Millikan's ultraviolet beyond 140A (copper condensed spark as source of light, see Fig. 4) with a second spectrograph. Prof. Lyman, at the Chicago meeting[5] showed what interest and results can be expected from this apparatus in joining the ultraviolet and x-ray spectra.

With a third spectrographic design, (plane ruled grating with 30,000 lines per inch) I measured[6] the *L* lines of iron, *K* of oxygen and carbon and *M* of molybdenum. A. Soltan[7] and myself published[8] studies of the *M* and *N* series of heavier elements and of the *K* series of lighter elements.

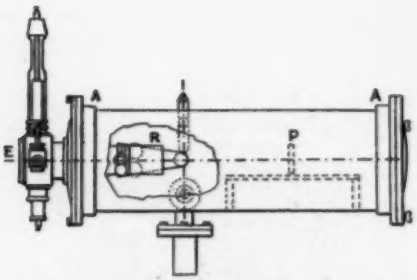


FIG. 2. *Apparatus with condensed spark chamber.*

Recently[8'] I obtained absorption spectra of soft x-rays and measured the *K* absorption edges of carbon, nitrogen and oxygen.

I. *Vacuum spectrograph*—We shall not return to the principle of the apparatus which has been fully described in former notes. The design in Fig. 1 shows the entire apparatus which has been constructed with the greatest care by the firm, Ch. Beaudouin[9] (Mr. Gondet, engineer). The dimensions of the cylindrical brass tube *AA* which constitutes the tight box are 60 cm in length and 18 cm in diameter. Figs. 2 and 3 show the disposition of the source, the two

[3] Comptes Rendus, May 10, 1926.
[4] Jour. de Physique, January, 1927.
[5] American Physical Society, February, 1927.
[6] Comptes Rendus, July 4, 1927.
[7] International Education Board Fellow.
[8] J. Thibaud and A. Soltan, Comptes Rendus, October 3, 1927. See also Jour. de Physique, November and December, 1927.
[8'] J. Thibaud, Comptes Rendus, January, 1928. Nature *3*, March, 1928.
[9] Paris, 31 rue Lhomond.

slits F, the grating R, and plate-holder P. The apparatus can be equipped, according to requirements, either with a condensed spark chamber E (Fig. 2) or with an x-ray tube (Fig. 3).

The source used at present is an x-ray metallic tube which is of particularly strong construction. It is of the hot cathode type with water cooling and removable anode. A water cooling appliance encloses the body of the tube. The conical joints, all removable, are made tight with rubber grease only. The cathode is insulated by a glass cylinder.

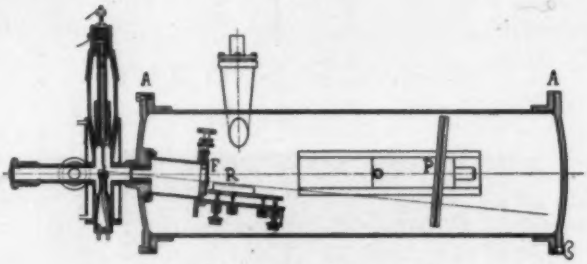


FIG. 3. *Spectrograph with x-ray tube.*

The vacuum is obtained by the aid of an helicoidal molecular pump which maintains the vacuum directly inside of the box of the spectrograph, and inside the x-ray tube, through a large lateral lead tube. These channels connected together by plane or conical joints can be easily removed. The pumping requires fifteen minutes from atmospheric pressure. Let us remark that between the target and the grating, two adjustable slits alone limit the narrow bundle of the useful rays, which pass through no material on their way to the plate. This is an important characteristic of this spectrograph as the absorbing power of a screen would disturb the bundle. This tube is maintained at constant voltage by means of a dynamo, with 50 to 100 ma current. All the spectra are obtained at fairly low voltage, between 900 and 1000 volts. The plane gratings set up on the adjusting appliance are always made of glass as we have found that this material is superior to speculum metal in reflecting power for soft x-rays.

The first grating, used in all our previous researches, had 200 lines per millimeter and gave, for ten minutes' exposures, four orders of the $K\alpha$ line of carbon $\lambda = 44.9$A, with a dispersion of 12.6 mm for the first and of 19 mm for the second order, the length between the plate and the grating being 40 cm. I am now using small-size pieces

of gratings placed at my disposal by Prof. R. W. Wood. Their surface, which is remarkably ruled, shows 1180 lines per millimeter (30,000 per inch). When used in my apparatus under tangential incidence they give very fine spectra with marked dispersion, the orders 1, 2, 3, of the $K\alpha$ line of carbon appearing (on plate at 40 cm) at 33 mm, 50 mm and 63 mm from the point of the reflected bundle (complement of the

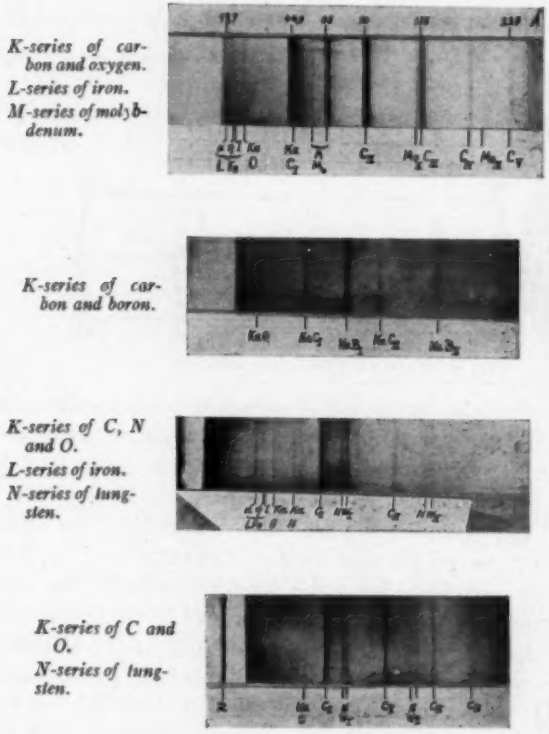

K-series of carbon and oxygen.
L-series of iron.
M-series of molybdenum.
K-series of carbon and boron.
K-series of C, N and O.
L-series of iron.
N-series of tungsten.
K-series of C and O.
N-series of tungsten.

FIG. 4. *Soft x-ray emission spectra (from Thibaud and Sollan)* (*full size*)

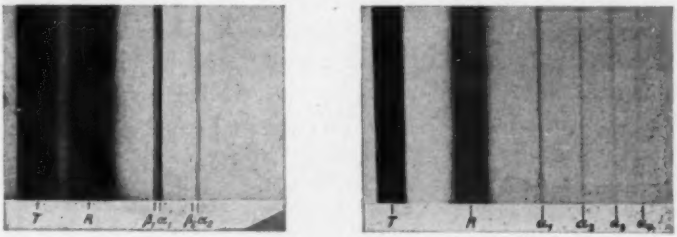
glancing angle upon grating: $\theta = 0.021$). In spite of the important increase of dispersion the intensity of the spectrum remains considerable, so that we use only ordinary plates, exclusive of Schumann plates. It is not even necessary to coat the plates with fluorescent oil.

In this way we have been able to photograph the spectrum at 40 cm in five minutes, expending only 10 watts in the tube. We are

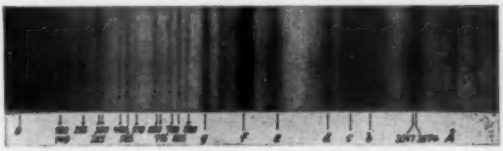
inclined to think that the transformation of the kinetic energy of the cathodic rays to x-rays takes place with higher efficiency at lower

1°/X-ray spectrum (Thibaud)

(*a*) *Copper spectrum* (*b*) *Iron spectrum*



2°/Extreme ultraviolet spectrum (copper spark) (Thibaud)



3°/Soft x-ray absorption spectra (Thibaud)

(*full size*)

K absorption edges of carbon, nitrogen and oxygen.

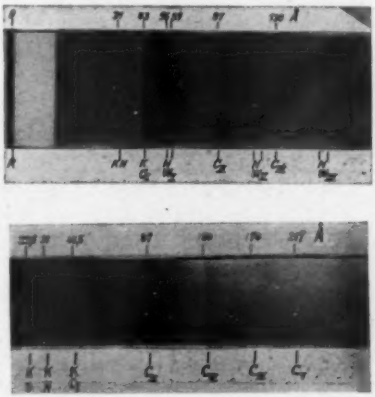


FIG. 5. *Grating spectra*

voltages. The cathode was made of platinum, tungsten or molybdenum wire or ribbon, often coated with oxides. In-lead wires were designed

for 20a and the end of the cathode terminal may be cooled by compressed air. In general the target was of iron.

II. *Soft x-ray spectra.* (a) *Emission spectra.* The illustrations in Figs. 4 and 5 show the general appearance of soft x-ray spectra obtained with a ruled grating. The spectra contain only a few narrow lines and closely resemble those of ordinary Röntgen rays. Spark lines and continuous radiations are not present.

I have attempted to obtain measurements of wave length in absolute value with some precision. The grating constant, determined by means of the line $\lambda = 5461$A of mercury, was found to be $d = 8477$A. The diffraction portion of the grating surface was reduced to a width of 1 mm by two collodion films deposited on the surface. The geometrical origin of the beam is therefore readily determined. All the linear and angular constants required for calculation are determined in recording the same spectrum at two different positions of the

TABLE 1. *Observed x-ray lines*

	Line	Wave length Angstroms	Volts	ν/R	Origin
K-Series	$K\alpha$ Oxygen	23.8	518	38.2	L_{II-III}
	$K\alpha$ Nitrogen	31.8	388	28.6	
	$K\alpha$ Carbon	44.9	275	20.3	
	$K\alpha$ Boron	68.0	181	13.4	
L-Series	$L\alpha$ Iron	17.7	697	51.4	
	$L\eta$ Iron	19.6	630	46.5	
	Ll Iron	20.1	614	45.3	
M-Series	*M* Molybdenum	65.0	190	14.0	$M_V - N_{II-III}$
		54.9	225	16.6	$M_{IV-V} - N_{IV-V}$
N-Series regular doublet	Tantalum	58.3	212	15.6	$N_{IV} - 0$
	$Z = 73$	61.4	201	14.8	$N_V - 0$
	Tungsten	56.0	220	16.3	$N_{IV} - 0$
	$Z = 74$	59.1	209	15.4	$N_V - 0$
	Platinum	48.0	257	18.9	$N_{IV} - 0$
	$Z = 78$	51.0	242	17.8	$N_V - 0$
	Gold	46.8	264	19.5	$N_{IV} - 0$
	$Z = 79$	49.4	250	18.4	$N_V - 0$

plate separated by a known distance. The values thus found for the constants were verified by the good agreement of the various values of the wave lengths of a single line, as measured on the plate in successive orders.

The results, obtained by the study of some sixty plates, are shown in Table 1, from Thibaud and Soltan. The relative values of the wave length (expressed, for instance, in relation to the $K\alpha$ line of carbon taken as standard) are not erroneous by more than one part per thousand. The absolute precision, account being taken of all sources of error is equal to 0.2 to 0.3A.

TABLE 2. *Width of several lines.*

Line	λ	Width in mm.	Width in A
$L\alpha$ Iron	17.7A	0.09	0.12
$K\alpha$ Oxygen	23.8	0.087	0.14
$K\alpha$ Carbon	44.9	0.43	0.90
M Molybdenum	65.0	0.15	0.42

We must remark that the width of $K\alpha$ C is noticeable (0.9A). On the contrary, the M line of molybdenum, although more dispersed, is much narrower. It does not thus seem that the lines of soft x-rays widen when their wave length increases. Some of these are wide by nature, such as the line $K\alpha$ of carbon. These particularly wide lines bear, very likely, a fine structure, resulting from the variations of the atomic energy levels in various chemical combinations of the atom.

III. *Low frequency levels.* The interpretation of the spectra gives several results relative to the low frequency levels.

(a) L_{II-III} *level of light elements.* The energies of $K\alpha$ lines of the following elements: boron, carbon, nitrogen, oxygen, fluorine[10] fall strictly in a straight line on the Moseley diagram. If on the other hand, we adopt the values given by Holweck[11] for the K absorption potential of these elements, we find, in subtracting, the energy of the L_{II-III} level, the following: fluorine, $L_{II-III}=12.2$ volts; oxygen, $L_{II-III}=10$ volts; nitrogen, $L_{II-III}=9$ volts; carbon, $L_{II}=7$ volts; boron, $L_{II}=10.6$ volts. The first four values lie on a straight line, which crosses the Moseley line (relative to the L_{II-III} level of the elements above $Z=10$) exactly at neon. Kossel's hypothesis is thus justified, viz. Moseley's line goes upwards when the level becomes a valence level (for elements below neon).

[10] Thoraeus and Siegbahn: Archiv. f. Mat. Astr. och Fysik, *18*, p. 1; 1925.
[11] De la lumiere aux rayons X (Presses Universitaires (1927)).

Boron is an exception. This is due, without doubt, to the high value for the K level by Holweck (192 volts). The L_{II} level of boron is correct when we adopt (from our value $K\alpha B = 181$ volts) for the K level of boron 187.5 volts.

(b) *M Series.* This series in the case of molybdenum must be reduced to a small number of lines, the N levels being incomplete yet for this element. The strong line $\lambda = 65$ A, which comes from $M_V N_{II-III}$ represents a wide extrapolation for the element $Z = 42$, of the lines $M_1 N_5$ observed by Hjalmar for the heavier elements and by Thoraeus for tungsten.

The weak line $\lambda = 54.9$ A could be due to the transition $M_{IV-V} N_{IV-V}$.

(c) *N Series.* A fine regular doublet ($\Delta\lambda = 3$A) belonging to the N series, appears for the heavy elements (gold, platinum, tungsten, tantalum). It is due to transitions from the O level (probably O_{II-III}) to the N_{IV} and N_V levels.[12]

ABSORPTION SPECTRA

In these earlier line spectra I have never noted the emission of a continuous radiation. Recently,[12'] however, using elements of high atomic weight as anticathode and intense electronic current in the tube (100ma), I have been able to demonstrate the emission of a continuous spectrum from solid bodies between 15A and 200A with properties similar to the independent background of a Coolidge tube.

The continuous background registered in my spectra is not uniform, but divided by a succession of fine bands with abrupt edges on the short wave-length sides (Fig. 5). The absorption of soft x-rays, then, varies discontinuously whenever the frequency of the independent radiation reaches a discontinuity of atomic absorption of elements present in the path of the rays. The elements present in the vacuum spectrograph, are carbon (vapor from grease used in joints), nitrogen and oxygen, and, in fact, we observe the intense K band of carbon (in five orders), and also of nitrogen and oxygen. The wave length of these K edges are as follows;

	λ(A)	V (volts)	ν/R
Carbon (C)	43.5	284	21.0
Nitrogen (N_2)	31.1	397	29.3
Oxygen (O_2)	23.5	524	38.7

in good accordance with Holweck's results from the ionization method.

[12] It is to be noted that the numerical accord, from Bohr and Coster's data, would be very good, taking N_{VI-VII} as the starting level. See Journal de Physique, December, 1927.

[12'] J. Thibaud, Comptes Rendus, January 30, 1928. Nature, March 3, 1928.

The absorption spectra reproduced in Fig. 5 are the first to be recorded by a photographic method in the gap between the ultraviolet and x-rays.

IV. *Refractive index for soft x-rays.* Recent researches have shown that for ordinary x-rays the refractive index μ is less than unity and that it can be expressed by the Drude-Lorentz formula:

$$\mu = 1 - \delta \qquad \delta = \frac{e^2}{2\pi m} \sum \frac{N_i}{\nu^2 - \nu_i^2}$$

This leads to the prediction (neglecting the characteristic frequencies for atomic oscillators) that δ varies as the square of the wave length.

As regards hard x-rays (δ order of 10^{-6}) the index being very close to one, the refraction is practically negligible for the selective reflection of this radiation inside a crystal. On the contrary, as regards soft x-rays, (δ predicted, order of 10^{-2}) refraction is quite noticeable and we must take it in account in the Bragg formula. Now all attempts to fill the gap between ultraviolet and x-rays are based on the turning crystal method (stratified coats of fatty acids with very long spacing). Refraction being then important, the measurements of wave lengths made by this method will show an important discrepancy in relation to absolute measurements such as those made by aid of a ruled grating.

This supposition is thus verified: If Dauvillier's data[13] be compared to mine, concerning lines $K\alpha$ of oxygen, carbon and boron; we observe that the values obtained with the crystal are systematically higher than those obtained with the ruled grating, and that furthermore, this discrepancy increases with wave length. The difference $\Delta\lambda$, negligible until 20A remains very near 1A between 20 and 50A, and reaches 5.5A for the $K\alpha$ line of boron. (Dauvillier finds 73.5A; I find 68A.)

From this discrepancy we can compute the refractive index of the fatty acid used as a crystal grating for the wave length $\lambda = 68$ A. We find

$$\delta = 1.2 \times 10^{-2}$$

A theoretical computation, account being taken of the K absorption of the oxygen and carbon atoms of the fatty acid leads (according to Kallmann-Mark formula[14] to:

[13] Journal de Physique, *8*, p. 1; 1927.
[14] Ann. der Physik, *82*, p. 585; 1927.

$$\delta = 1.0 \times 10^{-2}$$

in accordance with the experimental value.

We can then conclude that soft x-rays, as ordinary light and hard x-rays, show a refractive index which follows the Drude-Lorentz rule.

Then Thoraeus and chiefly Dauvillier note a widening of the lines when the wave length increases. The lines become broad and diffuse. We have not observed this phenomenon with use of ruled gratings. Even lines of great wave length remain tolerably narrow. The observation of the above mentioned authors is due to the crystal grating; in part because, on account of the high absorption coefficient, the number of reflecting planes effective in the diffraction is small and in part because of the refraction effect. Ewald has computed that in a crystal of index μ, the diffracted lines show an angular width:

$$\Delta\theta = 4\delta / \sin 2\theta.$$

This would lead a width of 7A for a line at $\lambda = 68$A with a fatty acid grating of index $\delta = 10^{-2}$. This agrees with the widening observed for the lines.

The effect of the refractive index is thus a serious difficulty in the extension of crystal methods to the longer wave lengths. Such difficulties are obviated by the use of the ruled grating at glancing incidence.

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Note added in proof—The grating spectrograph, with tube for soft x-rays, is now built for sale by the firm Adam Hilger, Camden Road, London.

THE SPOT OF LIGHT READING DEVICE FOR GALVANOMETERS

By T. Townsend Smith

I have recently had occasion to devise an optical projection system to be used for projecting a spot of light by reflection from a galvanometer mirror. Inasmuch as the conditions which determine the brightness of the projected spot are rather readily stated and seem not to be available in convenient form and as a projection system can be cheaply and readily built, some account of the matter may be of interest.

The projection system requires only spectacle lenses, which in an uncut form may be bought cheaply from any obliging dealer in spectacle lenses. The source of light which I have used is a 24 c. p. automobile head lamp, which is run by a small transformer—certain toy transformers answer nicely.

With such equipment we have a spot of light in our lecture room which can be used without darkening the room at all on a dull day and with only a moderate amount of shading on bright days. The diffused light in the room may be ample for, e.g., the taking of lecture notes by auditors and the lecture table may be brightly illuminated so that all apparatus and manipulation may be clearly discerned, and at the same time the spot of light, is bright enough for its position on the scale to be readily read. The scale is shielded from the direct light of the lamps above the lecture table but is not boxed in or shaded otherwise. If the room be darkened, three spots of light appear on the screen: —the brightest due to reflection from the silvered rear surface of the galvanometer mirror; a second spot, distinct in the darkened room due to reflection from the front surface of the galvanometer mirror; and a third spot, due to reflection from the cover glass of the galvanometer housing. These last two disappear when the shades are pulled up.

In our lecture room the distance from the galvanometer mirror to the scale is approximately eleven meters, and to get a bright spot at that distance requires some little attention to the design of the lens system. For shorter distances a satisfactory brightness may be obtained with less care.

THE PROJECTION SYSTEM

Fig. 1 represents the optical system which I have used. It is optically the same arrangement as that of the usual projection lantern with the

single exception that the width of the beam which forms the image, is limited, not by the aperture of the projection lens, L but by the diameter of the mirror M of the galvanometer. To simplify the figure the mirror is shown simply as an aperture and the beam is allowed to pass through this stop instead of being reflected at the mirror.

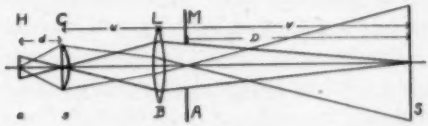

FIG. 1. *The lens system.*

Light from the head light bulb H is brought to a focus at the mirror M by the combined action of the condensing lens C and the projection lens L. The projection lens L forms an image of the condensing lens at the scale. This image is the spot of light, the movement of which measures the rotation of the galvanometer mirror. The image of a cross wire, or some other suitable marker at C is used as the reference mark for measuring the movement of the spot.

The image of the lamp filament formed on the galvanometer mirror has the appearance indicated in Fig. 2, the size of this image being dependent upon the focal lengths of the condensing and of the projection lenses.

FIG. 2. *Image of lamp filament on the galvanometer mirror.*

THE BRIGHTNESS OF THE SPOT

The illumination of the spot of light is dependent upon:

1. The brightness of the source of light, to which it is directly proportional. 2. The area of the galvanometer mirror, to which it is proportional in the most favorable case. In less favorable cases the illumination is proportional to the area of the illuminated portion of the mirror. 3. The distance from the mirror to screen, the illumination being inversely proportional to the square of this distance. 4. The amount of

light lost by reflection and absorption in the optical system. These conditions are probably apparent to photometrists, but not, I believe, to physicists generally. They are readily deduced.

The brightness b of a surface is defined as the light flux emitted per unit area of surface per unit solit angle. It is apparent from the definition that the light flux which will pass through a small area ds of the condenser lens C will be equal to

$$\frac{b \cdot a \cdot ds}{d^2}$$

where a is the area of the light source and where d is the distance from source to condenser lens, Fig. 1. Part of this flux will probably be intercepted at the mirror-stop M and hence will not reach the screen.

In order to get a uniformly illuminated spot of light on the screen, an image of the source needs to be formed on the mirror M and the useful cone of light is dependent upon the area A of the illuminated portion of the mirror. In the most favorable case this area is the area of the mirror. We have then that the useful flux of light, which leaves the area ds is

$$\frac{b \cdot B \cdot ds}{u^2}$$

where B represents the base of the useful cone at the lens L. This flux is distributed over an area dS of the screen, so that for the illumination at the screen one may write

$$b \cdot \frac{B}{u^2} \cdot \frac{ds}{dS} = b \cdot \frac{B}{u^2} \cdot \frac{u^2}{v^2} = b \cdot \frac{B}{v^2} = b \cdot \frac{A}{D^2}$$

where A is the illuminated area on the mirror M and D is the distance from the mirror to the spot of light, S. This last expression is the one desired.

It appears, then, that for a given distance D from galvanometer to screen the illumination of the screen can be increased only (1) by increasing the effective area of the galvanometer mirror or (2) by increasing the brightness of the source. An increase in the brightness of the filament of an incandescent lamp may be obtained only by an increase in the temperature of the filament and for a given lamp this would mean increasing the potential drop across the lamp.

It appears further that, except for light lost at the condenser, the illumination of the spot S is precisely as great as would be obtained if the lamp H were placed at C and the condenser lens were removed, an image of the lamp filament being formed at S. Ordinarily this image would not be as convenient as the spot of light and, as the gain in brightness at S is small, the spot of light is the preferable arrangement.

THE LENS BENCH

A sketch of a suitable lens bench is shown in Fig. 3, approximately to scale. The exact dimensions are obviously of no great importance.

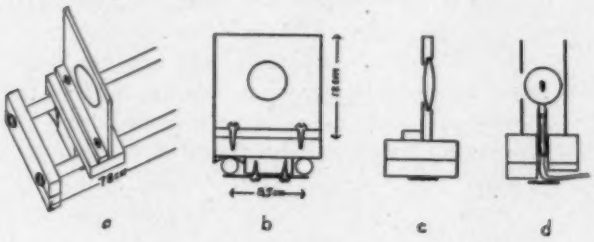

FIG. 3. *Bench and mounting for the optical system.*

The bench proper consists of two pieces of galvanized pipe (about $\frac{3}{4}$ inch outside diameter) set into wooden blocks for end pieces. The carriages are made of wood, except for a piece of spring brass which holds the carriage to the bench. A carriage is shown as mounted on the bench in Fig. 3 at *a*, in plan at *b*, and at *c* and at *d* are cross sections of a lens carriage and of the lamp support and housing.

No great range of adjustment for line is necessary. A side ways movement of the lenses of perhaps half an inch is provided by using slotted holes where the lens holders are screwed to the base blocks, and a vertical movement of the lamp is afforded by setting the lamp in a split brass draw tube, friction being ample to secure the desired stability of setting. The bayonet socket, which is customarily used in headlights, heats badly in this mounting and the lead wires are therefore soldered directly to the lamp terminals. The benches are merely blocked up to get the desired slope for the laboratory galvanometers. The lecture room bench is provided with levelling screws, though thin wedges would probably answer nearly as well in providing the somewhat finer and more convenient adjustment there desired.

EXAMPLES OF PROJECTION SYSTEMS

In Figs. 4 and 5, I have sketched two examples of the use of the projection system here discussed.

The example shown in Fig. 4 is of a galvanometer which is mounted in a corner of our electrical measurements laboratory. The galvanometer and lens bench are on a shelf, which is perhaps six feet from the floor and the spot of light appears on a scale in the corner, about two or three feet above the eye, the light being reflected from the mirror, and going above the lens bench to the wall. The lamp is run by a

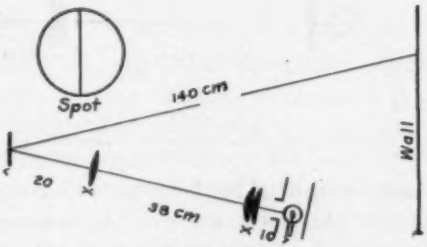

FIG. 4. *An electrical laboratory set-up.*

Thordarson "Danditoy" transformer, set at 7.5 volts, though I think the actual potential drop across the lamp is less than that. The spot of light is bright and clear, about 20 cm in diameter and the movement of the spot is indicated by the position of a vertical line, the image of a fine wire stretched across the back of the condenser lenses. The scale is divided to centimeters and is readily read to a tenth of a division, so that the sensitivity of the instrument is about 140/500 or .28 of the sensitivity which would be obtained with a telescope and scale at a distance of 50 cm.

The galvanometer is of the tripod pattern, with a plane mirror, and an aperture of about five millimeters. The projection lens is a double-convex 3 diopter spectacle lens, and the condenser system is composed of two 6 diopter periscopic lenses, the clear aperture being about 42 mm. The lamp housing is a short length of two inch sheet iron pipe, without a top.

The sensitivity would be improved by placing the lens bench above the galvanometer and making the reflected beam pass under the bench to form a spot on the wall just above the level of the eye, in which case smaller divisions on the scale would be serviceable. This would necessitate hanging the lens bench from the wall and rearranging

the whole set up. As the present arrangement is reasonably satisfactory, I have not as yet made the change in our laboratory.

The example sketched in Fig. 5 is the set up of our lecture room galvanometer. The galvanometer is on a shelf at one side of the room and the scale is in the corner across the room about eleven meters from the galvanometer. The 24 c.p. 6–8 volt lamp is run by a transformer

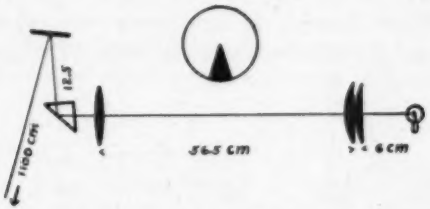

FIG. 5. *The arrangement lens system for lecture room galvanometer.*

at eight volts, and the spot of light is clear and sharp, as is indicated in the introductory paragraph above. The marker is of the type indicated in Fig. 5, such a marker being more legible than a vertical line to observers who are rather distant from the screen. The scale divisions are 5 cm. in length and hence the sensitivity is

$$\frac{1100}{50} \cdot \frac{0.1}{5} = 0.44$$

of the sensitivity of a telescope and scale at fifty centimeters.

The galvanometer mirror here used has a diameter of 1.25 cm. The projection lens system has a power of 1.87 (focal length about 53.5 cm) and is composed of a 1.5 and a 0.37 diopter spectacle lenses placed close together. The prism has a length of 2 cm on the edges of the square faces. The condenser system is composed of two 8 diopter periscopic spectacle lenses, the clear aperture being about 38 mm. The lamp housing is a short length of two inch pipe, provided in this case with a top to cut down the amount of stray light, which is not desirable in a class room.

FOCAL LENGTH OF THE PROJECTION LENS

There are two points which remain to be considered. The first is the question of what focal length the projection lens should have. Inasmuch as the brightness of the spot does not depend upon this focal length, the choice can be made on the basis of convenience.

The size of the filament spiral of the lamp is fixed and the size of the galvanometer mirror is fixed, so that the necessary magnification of the filament to satisfy the condition of maximum brightness is fixed, irrespective of the focal lengths of the lenses. If a short focal length projection lens is used, a correspondingly powerful condenser will be necessary, and convenience in this respect calls for as long a focal length as is feasible for the projection lens. This accounts for the rather odd combination of lenses in the projection lens for our lecture room galvanometer, as the system was fitted to a bench which had been previously built.

THE SENSITIVITY OF THE SPOT OF LIGHT METHOD

The other point is the question of the relative sensitivities possible with a spot of light and with a telescope and scale.

In the two examples here given of a spot of light, the sensitivity is less than with the ordinary telescope and scale reading device with the scale at 50 cm. I have convinced myself by trial that the spot of light may be made to equal or even to slightly surpass such a sensitivity of reading. Such a sensitivity is not, however, the limit with a telescope and scale. Using a telescope and scale and the half centimeter mirror referred to above, I have gotten at a distance of two meters, a sharp image of the galvanometer scale easily readable to a tenth of a millimeter, and I think that usable images could be obtained at a somewhat greater distance. The limit is, of course, set by the resolving power of the optical system. I doubt if it would be possible to match with the spot of light the sensitivity attainable with telescope and scale.

The advantage of the spot of light is one of convenience, and one must, I believe, be prepared to sacrifice a certain amount of sensitivity on the altar of convenience, if one wishes to use such a reading device.

Other examples of galvanometer spots of light will be found in the article on *Projection Apparatus* in volume IV of the *Dictionary of Applied Physics*.

For a further discussion of the general question of luminous intensity see, for example, Southall's *Geometrical Optics*.

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Matter, Electricity, Energy. By W. Gerlach. Translated from the German by Francis J. Fuchs,. xii+427 pages. D. Van Nostrand Co. New York. $6.00.

This is a translation of the German edition of 1926 practically without change. Many topics are included which are not ordinarily treated in accounts of experimental work on quantum theory such as,—atomic rays, dipole theory, nuclear disintegration, supraconductivity, conduction of electricity through crystals, the continuous x-ray spectrum, and characteristic infra-red frequencies. The chapters dealing with researches in which Prof. Gerlach has participated are especially interesting. Attention must be called to minor faults. There are numerous misprints and often the phraseology is not in agreement with the usual English rendering of German scientific terms. Usually however, the translation is clear and idiomatic. On page 98, the value of the Faraday is given as 96560 coulombs. It would be well if more American publishers would adopt the practice of furnishing an erratum slip.

The reviewer feels it is unfortunate that the author and the translator did not bring the book strictly up to date in issuing this edition. The spinning electron is barely mentioned. It is stated that the hypothesis "presents advantages only in the unification of the theoretical speculations. No experiment has as yet been published as a test for this theory; likewise no finding that would require a magnetic moment on the part of the electron." It is difficult to understand why spectral evidence on the spin of the electron should be held in such low esteem. Much interpretation is required in order to conclude from mechanical experiments that the individual atoms have quantized magnetic moments.

The chapter on atomic disintegration gives a false impression of the status of this subject. The results of the Vienna school are stated with a certainty which is unjustifiable even at the present time, to say nothing of the situation in 1926. On p. 309, it is stated that the photoeffect is independent of temperature. This is only a half-truth, in view of the work of Ives on the alkali metals. It must not be thought from these criticisms that the book is not an excellent one, for it does perform a definite service. It will be very useful to those who approach the subject for the first time, and the wealth of detail will make it interesting to those who, like the reviewer, find it impossible to read all experimental papers on atomic structure.

ARTHUR E RUARK